GROUTING EQUIPMENT MANUAL

SELECTION, OPERATION, MAINTENANCE, AND REPAIR

by Donald C. Hegebarth

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Foreword

Don Hegebarth has provided the grouting industry with a valuable and much needed resource through this *Grouting Equipment Manual*. Although a handful of textbooks are currently in print on the subject of grouting, they all address the subject of grouting equipment in a more or less general overview fashion. These existing texts primarily deal with geology and groundwater conditions associated with grouting in both soil and rock, materials to make the grout, grout rheology, engineering properties of the in-place grout, and so forth. Don's book is unique in its focus on dealing with the selection, operation, maintenance, and repair of the entire array of grouting equipment and accessories employed on most grouting projects.

I have worked with Don for the last 15 years or so of his 50-year career. He first worked in the field as a superintendent on tunneling and underground construction projects. In the second part of his career, Don worked with grouting plant and grouting system design and fabrication. When he retired from full-time employment, Don was the chief design engineer for ChemGrout. Over the years, he has also been involved with the Colorado School of Mines annual week-long "Grout Fundamentals and Current Practice" short course. In addition to giving a lecture on grouting equipment, Don has been in charge of organizing and coordinating the field demonstrations portion of the short course.

I believe that the grouting industry owes Don a big thank-you for writing this manual, as well as for his many years of contributions to the grouting world.

—Raymond Henn
Denver, Colorado

Preface

The purpose of this manual is to introduce various types of equipment employed in pressure grouting applications commonly performed in geotechnical works and to examine in detail the operating principles and maintenance issues relative to each type of equipment.

This manual is primarily intended for machine operators and maintenance mechanics, but it will also benefit specification writers, engineers, contractors, purchasing managers, and others who have a responsibility to specify, acquire, operate, or maintain pressure grouting equipment. Dialogue will be confined to mixers, agitators, pumps, and accessories. Discussion regarding electronic monitoring and other ancillary equipment will not be covered in this volume.

The term *pressure grouting* is a very broad category encompassing a wide variety of applications and operations. For example, some of these applications involve dam foundation grouting, soil stabilization, soil permeation, consolidation grouting, compaction grouting (except low-mobility), water cutoff and structural stabilization in rock tunnels, deep foundations via drilled piers, underwater concrete, structural concrete repairs, raising of settled slabs and structures, rock anchors, soil anchors, and machine foundations and bases. The applications for pressure grouting operations are almost limitless, as the equipment can be employed anywhere that a relatively fluid grout can accomplish the desired result.

Most of these applications involve using some type of cementitious-based grouting material to accomplish the desired end result. Whether prepackaged by the manufacturer as a brand name product or "homemade" by blending and mixing the materials onsite, the grouts used in construction and repair have one characteristic in common: they all have the ability to set up, or harden. This characteristic is necessary for the accomplishment of the task at hand, but it also presents unique challenges in the selection, operation, and maintenance of the grouting equipment. These challenges are discussed in detail.

For some of these types of applications, other materials such as chemical grouts are also available and effective, notably, for water cutoff and permeation grouting. But the preponderant material used for these and other applications has been, and still remains, some kind of cementitious material, usually portland cement based. This is because these operations often require large quantities of material, and cement is still the most economical material for these types of uses.

Whatever material is used, there are two basic elements common to all grouting jobs: (1) the material must be prepared, formulated, or mixed; and (2) it must be delivered to the injection site at a rate and/or pressure consistent with the requirements of the work to be accomplished or to conform with job specification requirements. This manual will deal almost exclusively with equipment designed and constructed specifically to prepare and deliver relatively fluid (high-mobility) cement-based grouts, whether portland cement or other types of cements that have similar properties. The properties of those materials are important and will influence the choice of equipment and how it is used and cared for.

Another intention of this manual is to help grouting machine operators perform their duties without unnecessary work stoppage from equipment that fails, so a primary focus is maintenance and repair of the various components common to most grouting equipment. Toward that end, detailed instructions for various maintenance and repair procedures are included.

Each manufacturer has unique design features and components that may require specific maintenance procedures; in those cases, it is best to consult their maintenance manuals. The purpose of this manual is to simply offer some very general suggestions regarding what to be aware of and how to avoid some common problems that can occur and how to deal with them when they do. This will be on the basis of more or less generic examples and are not intended to be specific to any particular machine.

When confronted with selecting equipment to perform a grouting application, the effect of the materials to be used in addition to the machine performance characteristics of mixing and pumping rates and pressures needs to be considered. Some of these characteristics will be discussed in the manual as well as whether they are a positive or a negative influence on the grouting application for which the equipment has been chosen.

Depending on the application and the materials to be applied, the mixer of choice may be as simple as a vertical shaft paddle mixer or equipment much more sophisticated such as a high-shear "colloidal" mixer, or in some cases a horizontal mixer such as a drum mixer or horizontal shaft ribbon blender. A wide variety of pumps are available for delivery of the mixed grout; some will deliver at a high rate of volume, some will produce high pressures, and some will do both. The selection of the correct pump for the particular application contemplated is of extreme importance, so each type of pump will be examined with respect to its operating parameters and the maintenance issues unique to each of them.

Despite the relatively "dry" subject matter, I sincerely hope that you enjoy reading this manual as much as I have enjoyed writing it, and that you find the information provided herein useful in the operation and maintenance of your equipment.

Given that the contents of this manual came as a result of a lifetime spent at work, it is difficult to name all the people who have contributed to my "education" over the years, but I would like to express my most sincere gratitude in particular to Ben Schatz and the folks at ChemGrout, who gave me the opportunity to become immersed in the design and manufacture of pumps and mixers to meet the challenges of difficult materials and a demanding industry; Dr. Raymond Henn, who encouraged me to share my experiences with this manual; Jane Olivier, who agreed to publish it; and finally, Diane Serafin, whose gentle guidance made completion of the manual possible.

1

Safety Considerations

The purpose of this chapter is to offer specific suggestions for procedures intended to help avoid injury. The remarks in this chapter are not meant to be preachy, or to restate the obvious, as is often the case with safety comments found in most tool and equipment owners' manuals.

An element of risk is certain when a machine is being worked on—skinned knuckles, pinched fingers, and the like, but there is also the potential for even greater injury, so before beginning any repair or maintenance procedure on a piece of equipment, make sure there is no possibility that the equipment could inadvertently be actuated, thus resulting in possible harm to yourself or damage to the machine. The suggestions that follow are intended to help prevent injury.

ELECTRICALLY POWERED EQUIPMENT

If the machine being repaired is electrically powered and is plugged into the electric source by means of an extension cord or some other device that is easily disconnected, it must be unplugged from the power source and the plug placed within sight of the mechanic where the work is being performed. This ensures that no third party, unaware that maintenance is in progress, will reconnect the power.

If the electrically powered machine is hardwired into the source, generally there will be a manual disconnect switch at the connection. If this is the case, use industry standard "lock out/tag out" procedures, which consist of physically locking the disconnect switch handle in the open position with a padlock or other device and attaching a tag to warn others that the machine is undergoing repair or maintenance. These steps ensure operator safety. Instances may occur when you are working in some relatively remote location where the normal "industry standard" procedures may not be recognized and equipment is hardwired directly to the source; nevertheless, you are responsible for your own safety, and even in this circumstance there are ways to disable the machine so that it may be safely

worked on. In any event, take whatever steps are necessary to prevent someone inadvertently starting the machine while it is undergoing maintenance or repair.

ENGINE-POWERED EQUIPMENT

When a machine is powered by a gasoline or diesel engine, it is usually apparent that the engine is either running or it is not, particularly if the engine is mounted on the machine's frame. However, some machines today are hydraulically driven and powered by a remote engine-driven power unit that may be located some distance from the equipment being repaired or maintained. Other job-site activities could make it impossible to hear whether the engine is running or not.

In cases where the engine is mounted on a common frame with the equipment, it is fairly simple to shut off the engine and put the key in your pocket. Nevertheless, there is always the possibility that someone else may have a second key, so it is wise to employ another layer of protection. To be doubly safe, if it is a gasoline engine, remove the spark-plug wire; if it is a diesel engine, shut off the fuel supply.

Although it is possible to find older equipment on which the various functions are driven by mechanical means, it is most common for engine-powered equipment to be driven hydraulically, and with some models of equipment, the engine may be integral to the unit and mounted on the same frame. Others may separate the engine from the mixing and pumping unit to create a remote power unit.

Generally, the hydraulic hoses that connect the grout machine with its remote power unit employ some type of quick-disconnect couplings; while these couplings allow hydraulic fluid to flow freely when properly connected, internal check valves in each half of the coupling prevent fluid from moving when the hose is disconnected. Therefore, if any of the hoses are disconnected, fluid will not flow and the engine cannot be started. However, to further ensure your safety, the hose that brings hydraulic power to the machine must be disconnected to make sure that no pressurized hydraulic fluid gets to the machine.

Although hydraulic oil is not classified by the U.S. Environmental Protection Agency as a hazardous substance, there is a rare possibility that certain hydraulic media may contain a very small amount of polychlorinated biphenyls (PCBs) that can pose a health hazard over time if exposure to the material is frequent or prolonged. When working with these materials, it is prudent to avoid contact with bare skin by wearing impermeable (e.g., rubber) gloves and clothing. Ingestion of PCBs from breathing fumes is so remote that the use of respirators is not considered necessary.

Most manufacturers' equipment manuals will contain specific comments relative to the hydraulic medium used in their machines, and it would be beneficial to read and understand this material before undertaking any work on the equipment that is likely to result in exposure to the hydraulic medium. In addition, manufacturers' manuals will usually elaborate on other safety procedures to observe while working on their equipment.

PNEUMATICALLY POWERED EQUIPMENT

Although machines powered by compressed air are less popular today than they were several years ago, many of these machines are still in service; in fact, for some applications, notably underground construction, they are still favored. Safety instructions for compressed air–powered equipment are similar to those that apply to electrically powered equipment in that it is always best to disconnect from the power source and bring the end of the hose within sight of your work area.

The difference between electrically powered equipment and air-powered equipment is that when the electric source is interrupted, the electrically powered machine is rendered inoperable. With pneumatically powered equipment, kinetic energy is stored in the air delivery system, which consists of the hoses and fittings used to bring the compressed air from the source (air compressor) to the machine. Therefore, it is not adequate to simply shut off the air supply at the source, because the air volume and pressure that remains in the delivery system can often be sufficient to cause injury if a function is accidentally turned on. Therefore, the compressed air stored in the delivery line must be "bled off" by opening a valve on the machine to relieve the remaining pressure until all pressure has subsided. Failure to do so may result in injury to yourself or damage to the machine.

CLEANLINESS

Grouting is a dirty business, and equipment as well as the equipment operators are going to be coated from time to time with cement dust, water, and fluid grout. While these factors will have an impact on operators and others in close proximity to the grouting operation, it is assumed that these personnel will have been supplied with the necessary personal safety equipment, such as dust masks, gloves, steel-toed work boots, and safety glasses. This discussion will focus primarily on the equipment. There is a threefold reason for keeping the equipment as clean as possible. First, the machine is much safer to operate when the valves and levers are kept clean and can be easily manipulated. Second, it is much easier to clean up after the production shift if the buildup is kept to a minimum during the shift. Finally, when it comes time to perform maintenance or repairs, it is much easier when one does not have to chip away at grout that has set up. Should it become necessary to chip away grout that has accumulated and hardened, remember to wear safety glasses to protect your eyes.

Although some products (including form release oil) claim that spray applied to the equipment prior to use will keep it fairly clean, these products seem to be marginally effective; by about mid-shift, their effectiveness has usually worn off and another application is needed. By this time, either the machine is already dirty and a second application will not help or the operator is too busy to stop and get the sprayer. However, water is always available (you're mixing grout, after all), so from time to time during the production cycle, whatever has built up during the work can be rinsed off. It is best not to let it accumulate.

During end-of-shift cleanup, mixers and agitators should be thoroughly scrubbed with stiff brushes while being flushed with clean water to remove all built-up deposits of grout material. This water, in turn, will be flushed through the grout pumps to be deposited in a washout pit or other facility provided for the disposal of grout residue.

Despite best efforts to conscientiously apply good cleaning methods, there may still be a small amount of suspended solids in the rinse water, which may settle out overnight in the mixing pump of colloidal mixers or in the valve chambers of plunger pumps, thus rendering the equipment inoperable the next day. A prudent operator will ensure that all rinse water is drained from all mixer, agitator, and pump components by opening drain valves or by removing any caps and covers as appropriate. Hoses should be thoroughly flushed with clear water and, if possible, either hung vertically (from a crane, perhaps) to drain or be blown out with compressed air.

Although good practice dictates that an attempt be made to finish the grouting procedure undertaken with the last bag of material mixed, there can be cases when a procedure ends abruptly, resulting in various amounts of mixed materials being unused, and ultimately wasted. Since portland cement grout is not considered to be hazardous nor classified as such, it may often be disposed of onsite by means of a washout pit excavated in the project site soil. Sometimes site conditions cannot accommodate a dedicated washout facility and excess grout and washout residue must be emptied into suitable containers for removal from the site.

2

Cement Grouts

SLURRY GROUTS

The simplest cement-based grout materials are slurries mainly composed of some kind of cementitious dry material and water. Slurry mixes are actually the bases and starting points for ultimately all grout mixes.

The most obvious of the cementitious materials that can be used for grout mixes are the various types of portland cement, of which there are five. They are classified by ASTM International (2012) and identified as follows:

- Type I (or Type I/II) is a general purpose cement most frequently used for grout and concrete.
- Type II has a low alkali content that provides moderate sulfate resistance. It is most often used in concrete that contains aggregate susceptible to alkali–silica reactivity. It is seldom used for grouting unless Type I/II composite cement is used.
- Type III is formulated for and used in concrete in which a high early strength is required; for example, patches in highway pavements where it is desirable to reopen the road as quickly as possible after repair. Type III cement is ground to a smaller particle size, making it a more desirable material than Type I or Type I/II for some grouting applications.
- Type IV is only used in mass concrete applications such as dam foundations and some structural foundations to reduce heat of hydration. It is seldom used for other purposes and never used for grouting.
- Type V cement is used in concrete that requires a high degree of sulfate resistance, such as sewage treatment facilities, digesters, and associated piping.

In the 1930s when the U.S. Bureau of Reclamation, the U.S. Army Corps of Engineers, and the Tennessee Valley Authority were building dams to provide flood control and hydroelectric power to many parts of the country, extensive slurry grouting was required to seal the rock on which the dams were constructed to prevent water from

escaping the pools through voids under the dams. This grouting was accomplished by drilling holes—often hundreds of feet into the rock—and injecting the rock features (seams, joints, bedding planes, etc.) with portland cement slurry grouts. A complex procedure of water testing and modifying the grout was used by means of adjusting the proportion of water to cement used in a mix, known as the water/cement (W/C) ratio.

Cement then (as now) was packaged in 94-lb bags that contained 1 ft^3 of bulk (loose) cement. So these early practitioners used cubic feet as their universal unit and measured their grout mixes accordingly; thus, a 1:1 mix was 1 ft^3 (7½ gallons) of water to 1 ft^3 of cement. A 2:1 mix was 2 ft^3 of water to 1 ft^3 of cement, and so forth, sometimes as great as 10:1. Increasing the water content while keeping the cement content the same results in thinner and weaker grout. At the time, there were few, if any, chemical products available to modify the grout properties with respect to penetrability into the rock. The grout operators could only change the W/C ratio to correspond with the particular requirements of the rock mass in which they were working.

Today, much has changed. Although W/C is still used to define the relationship of water to cement, the term has taken on new meaning because it relates to weight of water divided by weight of cement and is referred to as W/C by weight. So now, the original volumetric 1:1 mix of yesteryear becomes W/C = 0.66, where 62.45 lb (the weight of 1 ft^3) of water is divided by 94 lb of cement in today's denotation. Of course, when the amount of water increases, the W/C ratio exceeds parity, as would be expected. For example, the original 2:1 ratio becomes W/C = 1.33. In other words, the W/C ratio is still used to define the slurry mixes, but it is simply expressed differently today. A 1:1 mix by weight is understood to be *one 94-lb bag of cement and 94 lb of water.*

Another significant change has resulted in much more dramatic consequences. The advances in chemical research have led to the development of admixtures for grouting that have had a tremendous impact on the characteristics of ordinary portland cement slurry grouts, from grouts that resist washout or thinning when pumped into running water, to grouts that will not bleed (release excess water), to fluid grouts with W/C ratios as low as 0.25.

In addition, slurry grout characteristics can be modified by the addition of other cementitious products such as natural pozzolans, or artificial pozzolans such as fly ash, which are usually used to reduce the amount of cement needed to achieve a specific strength value or to add "lubricity" to the mix. Other admixtures, such as silica fume, tend to create a property of adherence or "stickiness" to the slurry grout mixture.

Slurry grouts continue to be used in dam construction all over the world to grout the rock masses on which the dams are constructed; however, they are also used to seep into certain types of permeable soils either to reduce permeability, thus preventing migration of water or other substances through the soil, or to strengthen the soil mass for structural purposes.

One of the characteristics most frequently sought from the slurry grout is the ability to penetrate small spaces. To a large degree this is a function of the grain size of the cementitious material. The smaller grain size of Type III cement as compared to the grain

Table 2.1 Characteristics of slurry grouts at various water/cement ratios

W/C	Water gal.	Water vol.	Water wt.	Absolute Volume, ft^3	Total Weight, lb	Unit Weight, lb	Specific Gravity per ft^3	Percent Solids wt.	Percent Solids vol.
0.310	3.5	0.48	29.16	0.95	123.16	129.64	2.078	76	51
0.350	4.0	0.53	33.32	1.01	127.32	126.06	2.02	74	47
0.399	4.5	0.60	37.49	1.08	131.49	121.75	1.95	71	44
0.440	5.0	0.67	41.65	1.15	135.65	117.96	1.89	69	42
0.487	5.5	0.74	45.81	1.22	139.82	114.59	1.84	67	39
0.532	6.0	0.80	49.98	1.28	143.98	112.48	1.80	65	38
0.576	6.5	0.87	54.15	1.35	148.15	109.74	1.76	63	36
0.620	7.0	0.94	58.31	1.42	156.48	107.26	1.72	60	32
0.665	7.5	1.00	62.48	1.48	160.64	105.73	1.69	59	31
0.886	10.0	1.34	83.33	1.82	177.33	97.43	1.56	53	26
1.33	15.0	2.00	124.95	2.48	218.95	88.29	1.41	43	19
1.77	20.0	2.67	166.67	3.15	260.67	82.75	1.33	36	15

Courtesy of Ben P. Schatz, ChemGrout, La Grange Park, Illinois.

size of Type I/II has often been a primary factor in choosing Type III cement as a grouting medium.

Over the years, the quest for the smallest grain size has led some material manufacturers to produce microfine and ultrafine cements with grain sizes even smaller than 15 µm. Because this manual is about equipment, not materials, this information is provided only to inform the reader that these materials exist. At the time of this writing, some ambiguity exists regarding the correct nomenclature for these cements, so the terms *ultrafine*, *microfine*, and sometimes *superfine* have been used interchangeably by grout operators and some manufacturers.

All slurries are best mixed through high-shear, high-energy colloidal mixers, and microfine and ultrafine slurries must be mixed through colloidal mixers to prevent agglomeration (the tendency for particles to cling together and form lumps).

Table 2.1 defines the characteristics of a slurry grout mix based on one 94-lb bag of portland cement (Type I, II, III, IV, or V) at various W/C ratios expressed as W/C by weight.

SANDED GROUTS

Before commercially manufactured structural grout materials became widely distributed and easy to obtain, it was common for grouting application contractors to formulate their own grout mixes onsite. These mixes consisted of various proportions of portland cement, fly ash, washed and graded sand, water, and usually some kind of admixture, generally a water-reducing admixture to reduce the water content, thereby enhancing the ultimate compressive strength of the resulting hardened material by means of reducing the W/C ratio.

These "homemade" mixes were used to create pre-placed aggregate concrete for structural repairs of bridges, dams, and other structures. They were capable of producing concretes with compressive strengths as high or higher than plant-mixed concrete of the day. Later, when more admixtures became available, it became possible to control the rheology and other properties of the grout material while even further enhancing compressive strength without sacrificing fluidity or pumpability.

Although the process of proportioning grout materials onsite is still a viable option today—in fact, more so today than ever, given the new admixtures available—few contractors use this option, choosing instead to purchase commercially pre-blended materials specifically formulated for specific applications (concrete repair, patching, etc.).

Sanded grout mixes are also used for a process known as claquage, or fracture compensation grouting, where grout is injected into soil to fracture and displace the soil mass either to improve the soil properties, such as load-bearing ability, or to compensate for settlement that may have been the result of a construction activity such as tunneling.

When using sanded grouts, the following considerations should be followed to ensure a smooth and successful application and to avoid unfavorable outcomes:

1. Prepare the material to achieve a consistency that is pumpable but not excessively fluid.
2. Use clean, washed, natural sand consisting of rounded particles and graded according to Table 2.2. Manufactured (crushed) sand is not recommended.
3. Keep hose lines as straight as possible; avoid loops, and make any bends in the line as wide as possible.
4. Pre-lubricate the hose line with a slurry mix of portland cement and water. Six or seven gallons of water per bag of cement is about right for this purpose. After the lubricating slurry is introduced, it may be immediately followed with the sanded mix.
5. Keep all hose or pipe joints tight; avoid leakage.

Gradation is one of the most important considerations when anticipating the use of sand in a grout mixture intended to be pumped. Gradation of a sand sample is determined by sieve analysis, which reveals the percentages of each individual particle size of which the sand is composed. Laboratory tests and field experience show that some sand gradations will pump much better than others, and some will pump only with difficulty. Grouts that contain sands consisting of only one or two sizes often cannot be pumped.

Another factor when considering the use of a sanded grout is the amount of sand that can be added to the base slurry mix. In general, this quantity will vary as a function of the particular gradation, but will usually be on the order of 1½ to 2 times the cementitious materials in the mix by volume. In some cases, it may be possible to exceed this proportion, but caution should be exercised lest the mixture become unpumpable because of excess aggregate volume.

A well-proportioned grout mix should retain the color of the cement from which it is made; if the completed mixture exhibits the color of the sand, too much sand has

been added. The ideal gradation values for sand in a pumpable structural grout mix are shown in Table 2.2 and Figure 2.1.

Table 2.2 Grouting sand gradation specifications

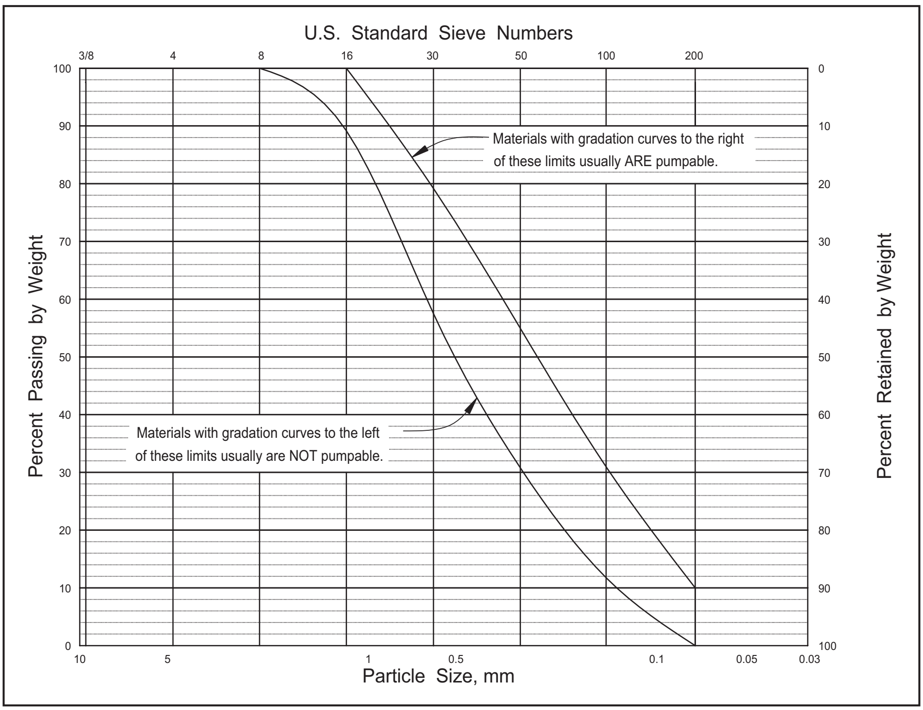
Sieve Size	% Passing
#8	100
#16	95–100
#30	55–80
#50	30–55
#100	10–30
#200	0–10
Pan	0–5

Source: Adapted from USACE 1980.

PRE-BLENDED, SANDED GROUTS

Many application contractors today prefer purchasing commercially produced, pre-blended materials rather than proportion grout materials onsite. These pre-blended materials usually have an aggregate component ingredient consisting of some kind of sand or other inert mineral filler. The stated purpose of the mineral filler is to enhance the strength of the material when in place, but not coincidentally, it also increases the volume of the material and thus reduces the price per unit to some degree.

If a commercially prepared, pre-blended grout is chosen, it should not be mixed in a colloidal mixer. In the initial stages of mixing in a colloidal mixer, a large amount of water



Source: Data from USACE 1980.

Figure 2.1 Grouting sand specification chart

is circulating at high velocity in the mixing tank. This water is many times the required W/C ratio of the material and will wash the aggregate portion out of the material, allowing it to fall to the bottom of the mixer, not to be retrieved until final cleanup. Instead, pre-blended materials should always be mixed in a paddle mixer or in the agitator tank of a colloidal grout plant.

On the other hand, if the material is proportioned onsite, a fairly thick cement slurry mix may be prepared. While in the mixing mode, the sand may then be added through the colloidal mixer to the slurry. Or the slurry could be transferred to the agitator tank and the sand added at that point. Either way would work, although adding sand in the agitator tank will save wear from abrasion to the colloidal mixing pump.

Given that manufacturers of these materials seldom consider pumpability, it is up to the contractor to test a few batches before committing to large-scale purchase of materials for any project. When a particular material that has been specified for the job proves to pump with difficulty, or perhaps not at all, sometimes it is possible to enhance pumpability by the addition of slightly more cement or fly ash to the batch, thus increasing the proportions of fines in the mix with which to carry the aggregate.

On the subject of pumpability, ChemGrout has extensively tested many brands and types of commercially produced, pre-blended grouting materials for pumpability and has posted the results on their Website, www.chemgrout.com. Since material manufacturers do not typically supply information relative to pumpability, these test results would be a good place to start when choosing the material to be used in a grouting project in which large quantities of grout will be pumped.

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3
Mixers

All portland cement grouting applications have two components in common: preparation of materials and delivery of the prepared materials to their final destination. In general, this involves some type of mixer for material preparation and a pump for delivery.

Depending on the application and the materials to be applied, the mixer may be as simple as a vertical shaft paddle mixer or a much more sophisticated one such as a high-shear "colloidal" mixer, or in some cases a horizontal shaft ribbon blender. Each of these mixers are discussed in this chapter to learn their characteristics and determine what maintenance they require to keep them operating at optimum efficiency. Pumps are discussed in detail in Chapter 4.

PADDLE MIXERS

The most common type of mixer employed for the preparation of portland cement–based grout materials is the vertical shaft paddle mixer. Although not particularly efficient when compared with other types of mixers—the colloidal mixer, for example—they are simple, rugged, and inexpensive. Furthermore, they are still the best mixer to use for the preparation of pre-blended, sanded mixes. A schematic diagram for a typical pneumatically driven paddle mixer is shown in Figure 3.1.

These mixers usually consist of a vertically oriented cylindrical tank with horizontally oriented paddle arms mounted on and rotating around a vertical shaft. The shaft is driven by some means, usually mounted at the top of the tank. This driver can be an electric or pneumatic motor driving the paddle through either a right-angle or vertical speed reducer or a hydraulic motor directly driving the paddle shaft.

One advantage to the pneumatically or hydraulically driven paddles is variable speed control, allowing the paddles to rotate at 90 to 100 rpm for mixing, and to be slowed to about 40 to 60 rpm when used as an agitating holding tank. Electrically driven paddles are usually fixed speed and if configured for mixing are generally too fast for agitating. Conversely, if they are configured as agitators, they are generally too slow for mixing. Speed control is possible through the use of phase converters or variable frequency drives,

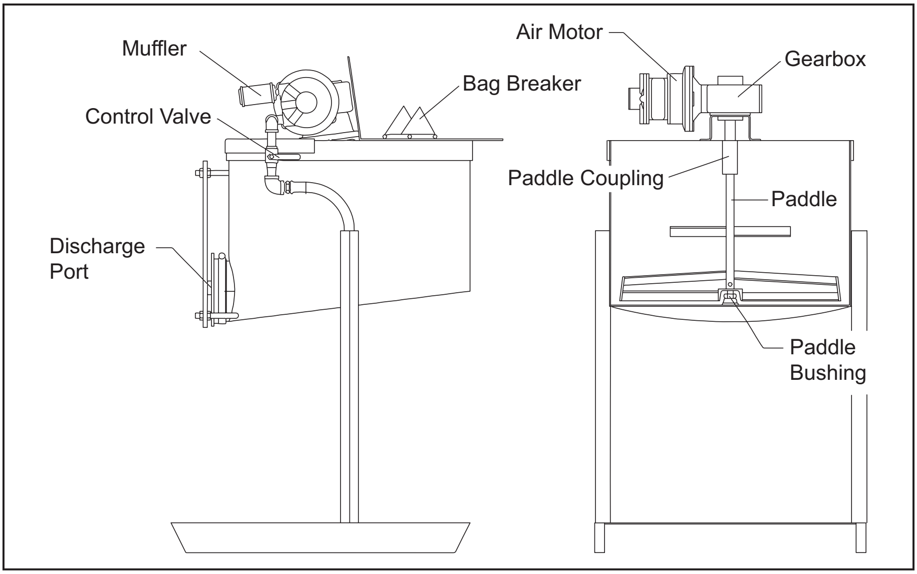
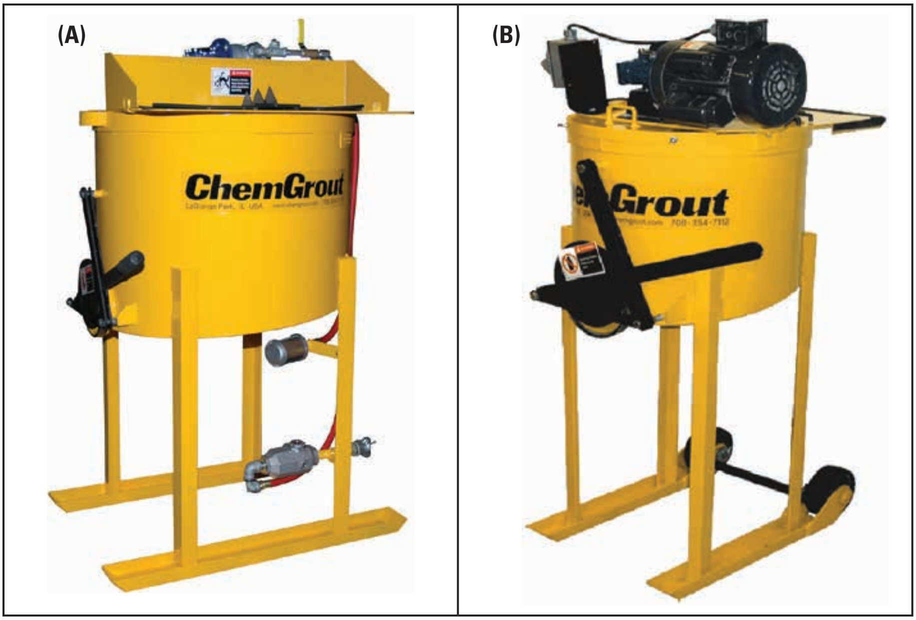


Figure 3.1 Typical pneumatically driven paddle mixer



Courtesy of ChemGrout.

Figure 3.2 Typical paddle mixers: (a) pneumatically driven and (b) electrically driven

but they add a layer of complexity to the motor control system and can result in reduced torque when the motor is slowed down.

Because the natural motor speeds are far in excess of those required for either mixing or agitation, both pneumatically driven and electrically driven mixers (Figure 3.2) use gear reducers to decrease the motor speed to the correct values for these purposes. Assuming the lubricating oil is changed at manufacturer-recommended intervals, these gear reducers should last indefinitely; however, under heavy use, it is sometimes necessary to replace one or more internal parts, such as bearings, ring gear, or worm gear, due to wear or imposed damage. This is discussed in detail in Chapter 6, Power Transmission.

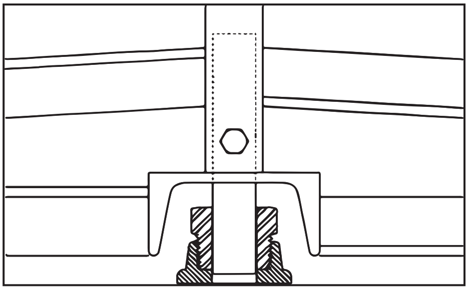


Figure 3.3 Paddle pin and bushing

Finally, there is usually some type of supplemental support device for the paddle to compensate for lateral loads, either in the form of a top-mounted bearing or a shaft bushing in the base of the mixer (Figure 3.3). These need to be inspected regularly for wear, lubricated (in the case of the bearing), or replaced when excessive wear is noted. The paddle pin may be removed from the paddle, turned end for end, and replaced back into the paddle until both ends of the pin are worn and replacement with a new part is required. The paddle bushing is threaded into a flange welded to the bottom of the mixing tank and may be unthreaded and replaced with a new part when it becomes worn.

Courtesy of Häny AG.

Figure 3.4 Electrically powered agitator

Agitators

Because of their similarity with paddle mixers, agitators have been included within this category. The purpose of an agitator is to act as a reservoir of mixed grout, keeping the solid particles in suspension in preparation for pumping. In general, regardless of size or capacity, most agitators are usually almost identical to paddle mixers, except that some electric-powered agitators are

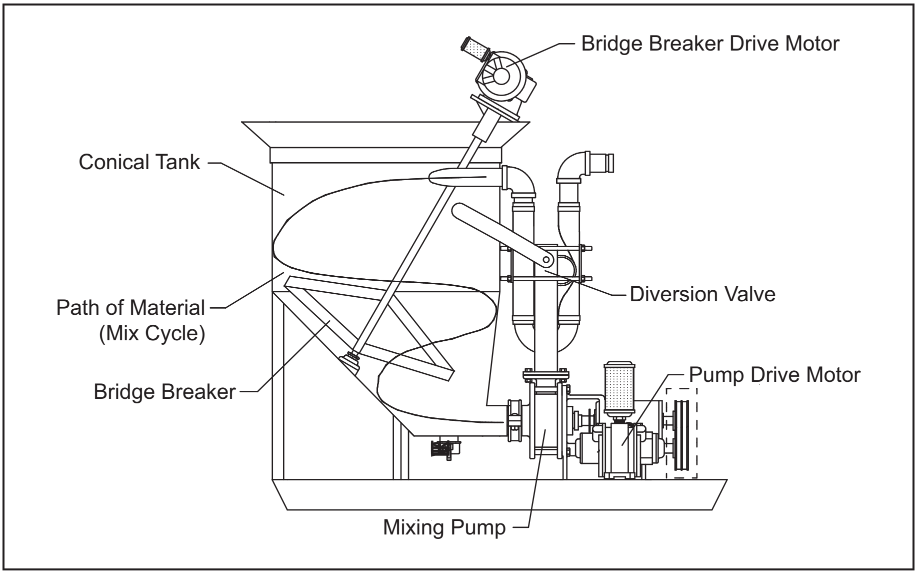


Figure 3.5 Colloidal mixer

only single speed (Figure 3.4). Mixers can usually be used as agitators, but not all agitators can be used as mixers.

Whereas the mixer may discharge directly into either a pump or an agitator, the agitator is often permanently plumbed directly to the pump. To be fully effective, an agitator should have a volumetric capacity at least 1½ times that of the mixer to ensure that there is always sufficient grout for the application to avoid shutdowns as a result of insufficient material.

Maintenance and Repair

The very simplicity of paddle mixers ensures that maintenance issues are kept to a minimum. Simply keeping the machine as clean as possible and changing the paddle bushing or pin when it becomes worn is the only maintenance required. Repair procedures will only be required to the driving components, such as motors and gearboxes.

Pneumatic motors may require rebuilding after a time, and the motor manufacturers provide service kits for that purpose. Pneumatic motor repair is discussed in detail in Chapter 5, Power Options. In the case of electrically or hydraulically driven mixers, there is virtually no need to change or service the electric motors under normal usage. Gearbox repair procedures are described in detail in Chapter 6, Power Transmission, in which common gearbox repairs are described and illustrated.

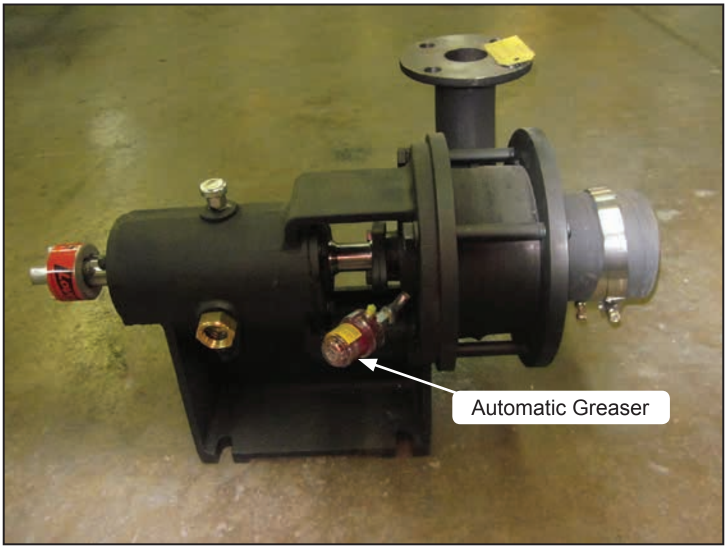


Figure 3.6 Typical colloidal mixing pump. Note the automatic greaser for shaft seal lubrication.

"COLLOIDAL" MIXERS

The term "colloidal" is not strictly correct as applied to mixers; a more accurate term to describe these mixers would be "high shear" or "high energy." Although the high amount of energy focused within the mixing apparatus literally forces the solid particles apart, contributing to more thorough and complete wetting of each individual particle, the resulting material, despite relatively high solids content, cannot be accurately described as a true colloid.

In general, materials are added to a roughly offset, cone-shaped cylindrical container. Fluids (water) are added first followed by the solids. Then some type of mechanical device (mixing pump or colloidal mill) accelerates these materials to a high rate of linear velocity and returns them tangentially into the tank for another cycle, as schematically diagrammed in Figure 3.5. When the mixing cycle is complete, the mixed materials are transferred to a reservoir (agitator) in preparation for delivery, or they can be discharged directly into a grout delivery pump.

The device used by most commercially available colloidal mixers to accelerate the material being mixed performs two basic functions. First, the material is accelerated to a high rate of turbulent flow within the discharge piping, and in so doing, a great deal of shear energy is imposed on the material passing through the mixing device to ensure that most, if not all, of the cement particles are separated from one another and completely wetted. In most colloidal mixers, this device is some kind of specially designed centrifugal pump incorporating an open-faced impeller capable of imparting high-shear forces on the material being mixed, as illustrated in Figure 3.6. Second, after the material is thoroughly

Courtesy of Team Mixing Technologies.

Figure 3.7 Cutaway colloidal mill showing discar

mixed, the pump is then used to transfer the grout to an agitating holding tank by means of moving the diversion valve from the "mixing" position to the "transfer" position.

Although all colloidal mixers work essentially in this way, there are some design variations. For example, Colcrete employs a device called a colloidal "mill" to accelerate the material. The material in the tank enters the mill radially where it is picked up, accelerated, and radially expelled back into the tank by a rapidly rotating discar mounted on a horizontal shaft. Considered by many to be the original colloidal mixer, if it is not, it is certainly among the first, having been in continuous production since the late 1930s. Figure 3.7 shows one of these mixers with a portion of the colloidal mill cut away to expose the discar.

Other manufacturers such as Atlas Copco Craelius, AB, ChemGrout, and Häny AG, to name a few, use various types of centrifugal pumps to accelerate the material. Depending on the manufacturer's preference, these pumps may be mounted horizontally or vertically; in a few cases, the impellers are mounted horizontally at the base of the tank, being driven through a vertical shaft by a motor at the top of the tank. These pumps may be driven by pneumatic or electric motors, either direct-coupled as shown in Figure 3.8 or attached through an arrangement of sheaves and belts as shown in Figure 3.9. Regardless

of orientation or drive mechanism, the ultimate purpose and result is the same: to rapidly produce stabilized colloidal grout mixes.

Colcrete has produced mixers specifically for sanded mixes, which are essentially two-stage mixers. The first stage mixes the slurry portion of the mixture with the sand added during the second stage to complete and deliver the finished product.

Figure 3.10a depicts the slurry mixer mixing water and cement slurry while the sand mixer is discharging sanded grout to the agitator or grout pump. Figure 3.10b shows the slurry mixer discharging slurry to the sand mixer where the sand is being added to the slurry and thoroughly mixed into the finished product of sanded grout.

The specifications of grouting projects often require that colloidal mixers rotate at speeds of 1,500 to 1,800 rpm. The reason for this is because most colloidal mixers in the United States were manufactured in Europe for many years and were driven by direct-coupled electric motors. When operated on the 50-Hz (hertz) European power grid, they rotated at about 1,500 rpm; when powered at 60 Hz in the United States, the motors then turned at 1,800 rpm. (This is discussed further in Chapter 6, Power Transmission). Because drive options other than direct-coupled electric motors make possible much higher rotational speeds, some of those specifications have been revised or rescinded.

Courtesy of Häny AG.

Figure 3.8 Electrically powered direct-drive colloidal mixer

Figure 3.9 Air-powered, horizontally mounted colloidal mixer

Maintenance and Repair

Regardless of configuration or driving mechanism, these mixing pumps all have one thing in common: they are rotary devices. Therefore, each pump has some kind of shaft seal that needs periodic attention. In some cases, the shaft seal is simply braided graphite packing,

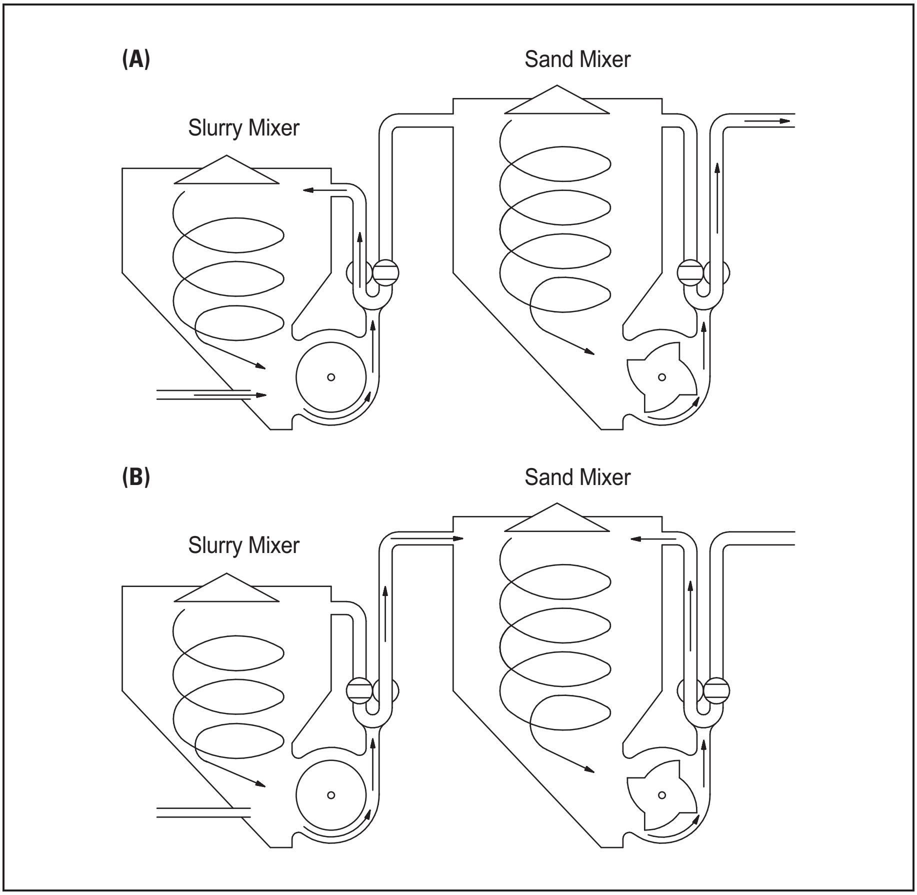
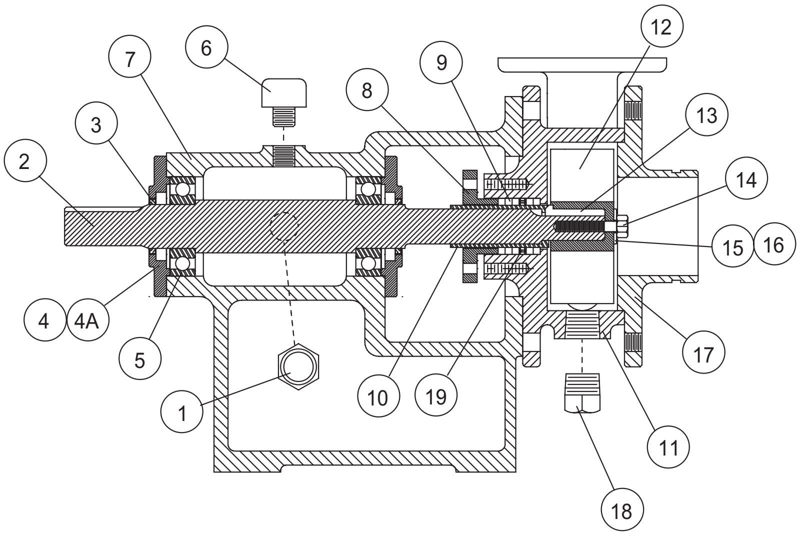


Figure 3.10 Two-stage colloidal mixer

which needs to be lubricated daily, and in other cases, a mechanical type seal may be employed. In either case, these must be monitored for leaks, and when leakage is detected, appropriate action must be taken to prevent damage to the shaft.

In addition to the shaft seal or packing, the next most commonly replaced item is the impeller. The impeller is in constant high-speed contact with abrasive grout materials and can be worn to the extent that the mixer eventually becomes ineffective. For this reason, mixing pump volume and pressure should be constantly monitored for signs of wear and replaced according to manufacturers' instructions.

Although some manufacturers permit sanded mixes to be put through their colloidal mixers, it stands to reason that an abrasive mixture being accelerated to high speed will have a negative effect on the longevity of any wear parts exposed to the material, so this



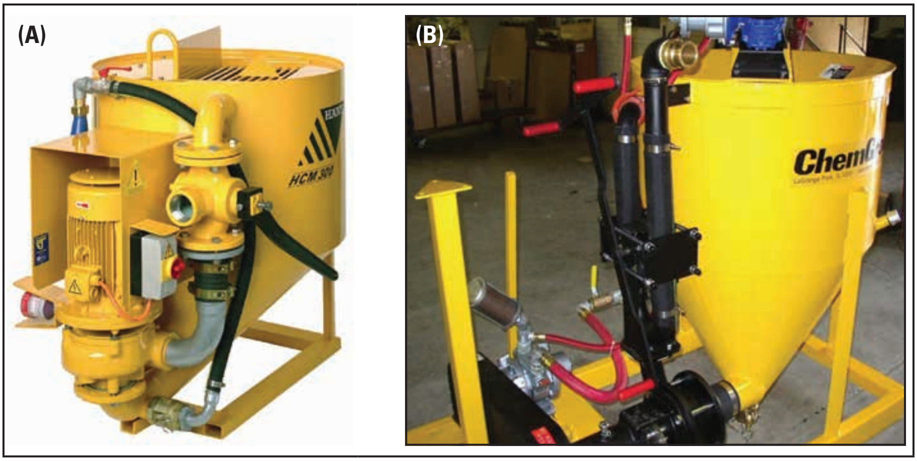
1	Oil Sight Gauge	10	Shaft Sleeve
2	Shaft	11	Pump Case
3	Oil Seal (*2 required*)	12	Impeller
4	Bearing Cover (*2 required*)	13	Impeller Key
4A	Bearing Cover Gasket	14	Impeller Bolt
5	Bearing (*2 required*)	15	Impeller Washer
6	Vent Cap	16	Impeller Lock Washer
7	Pedestal	17	Suction Cover Assembly
8	Packing Gland	18	Drain Plug
9	Packing Set	19	Lantern Ring

Source: Data from ChemGrout 2007.

Figure 3.11 Mixing pump repair parts drawing for 2 × 3 × 6 colloidal mixing pump

author's recommendation is to restrict the use of colloidal mixers to slurries only, adding sand to the agitator, if necessary.

The most frequent repair procedure on any centrifugal type mixing pump is periodic replacement of the shaft seal, which is referred to as "packing" in Figure 3.11. The shaft seal usually consists of several rings of self-lubricating packing material, generally a graphite-impregnated rope formed in a square cross section and of a dimension to fit the space between the shaft and housing. These rings are fabricated from straight lengths of the packing material, which are cut such that they will just fit around the shaft. The cuts are made at an angle so that when the packing ring is installed in the pump, the ends overlap and form a positive seal when pressure is applied by the packing gland.



Courtesy of Häny AG. Courtesy of ChemGrout.

Figure 3.12 Colloidal mixer diversion valves: (a) plug valve and (b) pinch valve

Replacing the shaft seal is simple:

1. Loosen or remove the nuts holding the packing gland (no. 8), as illustrated in Figure 3.11, and move the packing gland back on the studs and away from the pump.
2. Using either a corkscrew-type packing-removal tool or steel picks, remove the existing packing from around the shaft. If the pump has a lantern ring (no. 19), as illustrated in Figure 3.11, remove it as well as any packing ahead of it.
3. Replace the removed packing with fresh packing, installing the same number of rings that were removed before and after the lantern ring, then return the packing gland into position, and replace and tighten the nuts just enough to set the newly installed packing.

The interval between packing changes can be dramatically extended by conscientiously keeping the packing lubricated with any kind of good grease applied on a daily basis through grease fittings located near the lantern ring position. Better yet, installing an automatic greaser, as shown on the mixing pump in Figure 3.6, will help prolong its life because it feeds a constant supply of grease to the packing.

Maintenance items unique to the colloidal mixers are the diversion valves. Some mixers employ a plug valve as shown in Figure 3.12a, which, as the name implies, consists of a cylindrically shaped steel plug retained within a heavy cast housing and bored laterally with holes that will direct material either back into the mixing tank or to discharge from the mixer, depending on the position of a handle affixed to one end of the plug. A grease fitting is provided to keep the valve lubricated for proper operation, but from time to time the valve should be disassembled for inspection and to replace seals.

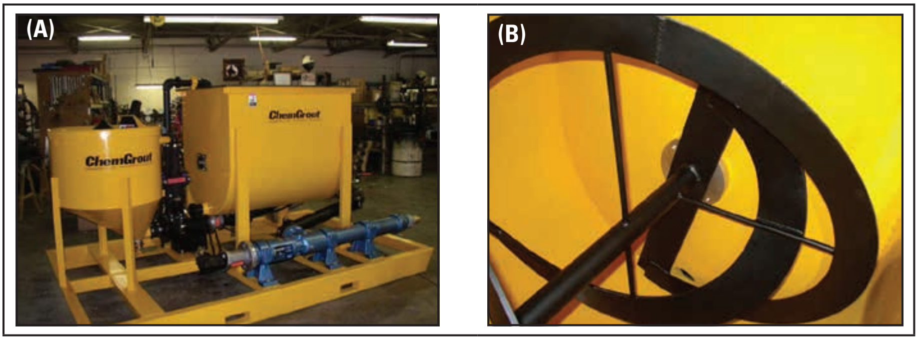


Figure 3.13 (a) Ribbon blender (with mixer and pump) and (b) detail of blender ribbon

Some manufacturers use a simple pinch valve, as shown in Figure 3.12b, that diverts the mixing pump discharge from the mixing tank to discharge into an agitator in preparation for pumping. A U-shaped pipe is attached to the discharge port of the pump, which allows the material to be discharged simultaneously into two flexible hoses; one hose returns material to the mixing tank, and the other directs material away from the mixer. A lever-operated cam is situated between the hoses to enable the operator to pinch closed one or the other of the hoses, thus directing the flow of the material. If the mixer uses pinch valves, the hoses and cam need to be greased periodically to keep them operating smoothly, and the hoses will need to be replaced from time to time when signs of wear are apparent.

RIBBON BLENDERS

A ribbon blender is essentially a U-shaped tank with two concentric, helical ribbons of opposite hand rotation mounted on a horizontal shaft and rotated at speeds up to 80 rpm by means of electric or pneumatic motors through a gearbox or driven directly by hydraulic motors (Figure 3.13).

Ribbon blenders are seldom seen on conventional grouting projects, but they are gaining popularity with operators who apply cellular concrete products such as fire door insulation and flowable fill materials, which are often used for mine and tunnel backfill because they can blend a number of constituents in very lightweight and fluid materials to produce a uniform specific gravity throughout the material mass.

Maintenance and Repair

Other than maintaining the gearbox as on the paddle mixer and keeping the shaft seals (which are essentially stuffing boxes with braided graphite impregnated packing similar to mixing pump shaft seals) tight and well lubricated, there is very little maintenance to be done to keep these mixers operating efficiently.

CONTINUOUS MIXERS

Courtesy of ChemGrout.

Figure 3.14 Continuous mixer/pump

Continuous mixers, such as the one illustrated in Figure 3.14, have little or no utility in a geotechnical context, but nevertheless, they are included in this chapter. Within their particular industry they have become almost absolutely essential to operators who use low-density materials such as floor toppings and underlayments as well as some spray-applied products.

Solid materials in the form of pre-blended powders are added to the machine hopper. Then a dosing device, such as a wheel with pockets or buckets, deposits metered amounts of the material into the mixing chamber at a regulated rate where water is added in just the correct quantity and at just the correct rate to turn the dry material into a usable slurry.

Successful performance depends on balancing the rate of dry material with the rate of water and ensuring that all machine parameters, such as rate of solids delivery and water pressure, remain balanced throughout the operation.

Generally, once all of the variables have been adjusted satisfactorily, these machines perform quite admirably in a high-production-capacity environment.

Maintenance and Repair

A continuous mixer is designed to require very little maintenance other than the normal common-sense procedures related to keeping the machine clean. For proper operation, it is necessary that the mixing tube, mixing shaft, powder feed wheel, powder hopper, and the opening from the powder hopper to the mixing bowl be kept free from material buildup.

In addition, the electrical panel must be kept free of splashback from water or mixed materials. The panel should be opened periodically and inspected for powder buildup, although this is not likely to occur because of the impervious gasket around the door. But if powder intrusion is noted, it may be removed with a shop vacuum and small brush.

The water filter in the pressure reducer should be removed and cleaned at the beginning of each work day, being careful to correctly position the O-ring when replacing the plastic cap over the filter.

Because the machine will be operated in a dusty environment, it is good practice to remove and clean the two air filters on the air compressor at least once a week to keep the compressor operating at optimum performance.

The most frequent repair procedure is replacement of the progressing cavity pump stator. This type of machine is designed to be easily disassembled into its component parts for ease of transport within the buildings in which it is most often employed. The rotor and stator are disassembled from the machine as a unit, so the rotor can be removed from the stator and replaced quite easily.

REFERENCE

ChemGrout, Inc. 2007. *CG-600/3L6/A Operating and Maintenance Manual*. La Grange Park, IL: ChemGrout.

4

Pumps

A wide variety of pumps are available for delivery of mixed grout. Some will deliver at high volume, some will produce high pressures, and some will do both. The selection of the correct pump for the particular application is of extreme importance. Each type of pump is examined in this chapter with respect to their operating parameters, and maintenance issues unique to each of them are explored.

RECIPROCATING PUMPS

Reciprocating pumps are the class of pumps that operate in a linear rather than rotary motion; that is, the pumping element, whether it is a piston or plunger, moves back and forth in a linear fashion within a confining element such as a chamber or cylinder.

Piston and Plunger Pumps

Figure 4.1 illustrates the differences between the two most prominently used reciprocating grout pumps: piston and plunger. The piston pump, shown in Figure 4.1a, exhibits a basically cylindrical shaped piston with a relatively flat face making contact with the process material to be pumped. Sealing elements that comprise part of the piston itself are in constant contact with the pump cylinder wall, preventing passage of the process material past the piston. Ball valves are common to both types of pump. As the piston retracts, the upper ball is drawn downward, allowing material from the hopper above (not shown) to enter the pumping chamber while, simultaneously, the discharge valve ball is seated to prevent material already pumped to back up into the chamber. As the piston moves forward (as depicted in the drawing), the upper ball is seated and the discharge ball is unseated, allowing the material in the pumping chamber to be discharged and sent to the work site.

The forward stroke of the piston pump evacuates the volume of material that entered the pumping chamber during the retraction stroke. The discharged volume of material may not necessarily equal the calculated discharge volume per stroke due to several

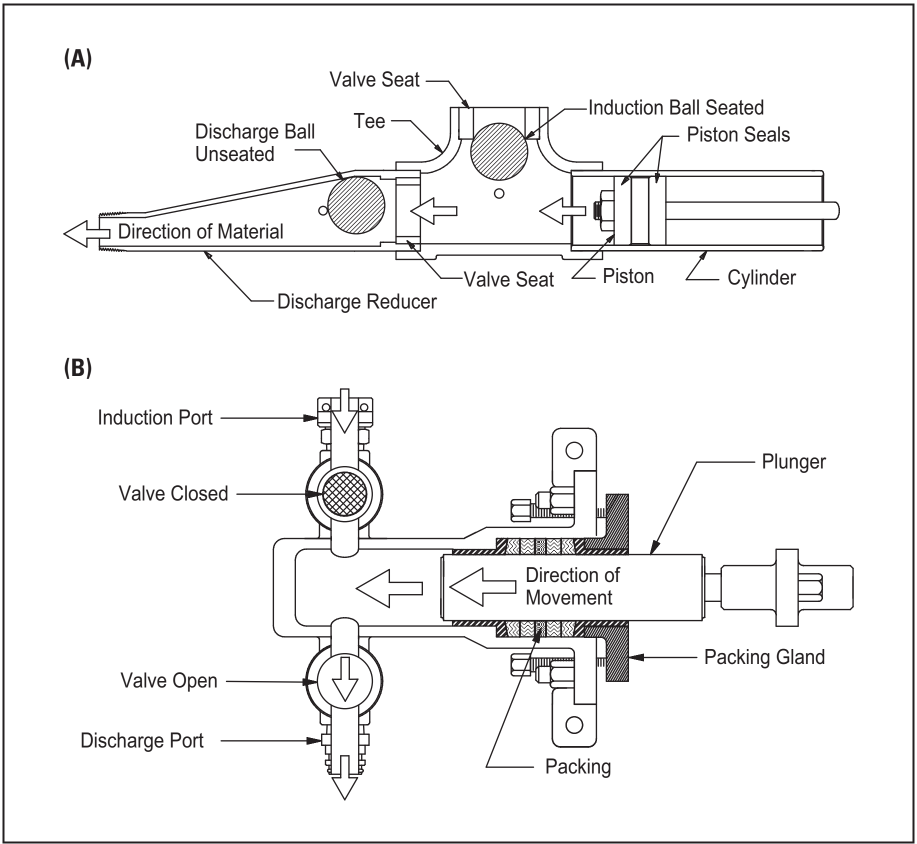


Figure 4.1 (a) Piston pump and (b) plunger pump

factors, which may include incomplete filling of the pump chamber, imperfect seating of the valve balls, or short stroking of the piston. Nevertheless, for the purposes for which it is used, an efficiency factor of 80% to 90% is considered sufficient; however, because of these factors, use of piston strokes to estimate quantities pumped should be avoided.

Figure 4.1b is a representation of a typical single-acting plunger pump. In this pump, the packing forms a seal between the pump casing and the solid plunger. Adjustable packing glands hold the packing firmly in place within the pump body and around the plunger. The plunger does not contact the wall of the pump cylinder. The plunger pump operates the same way as the piston pump and incorporates the same type of ball valves; however, they are fabricated of different material and differently arranged to ensure quicker and more positive closing between strokes, thus enhancing efficiency. As the plunger retracts from the valve boxes, material is drawn into the pump cylinder

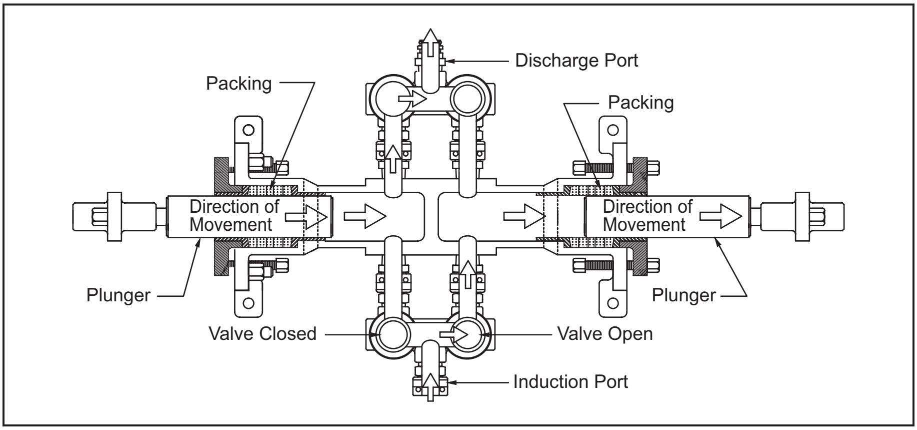


Figure 4.2 Double-acting plunger pump

through the induction port. As the plunger extends, the material that was drawn in is now expelled through the discharge port.

Each of the pumps shown in Figure 4.1 are single acting; that is, they can discharge only on the extend stroke of the driver, using the retract stroke to refill the pump chamber with process material. Since this action creates uneven pressure spikes considered to be detrimental to most kinds of grouting applications, efforts have been made to mitigate the problem by evening out the flow rate. Manufacturers have accomplished this by adding another pumping element of equal capacity to the first, but they work contrapuntally; that is, while one pumping element discharges, the other fills and vice versa during the same time, thus evening out the flow and reducing pressure spikes.

This can also be accomplished by using two identical pumps, each with its own driver, but timed so that they pump intermittently, thereby evening the flow rate and reducing pressure spikes. An example of this method is shown later in Figure 4.14. Another method also uses identical pumping elements, but they are arranged in a linear fashion to fully utilize both strokes of the same driver. In other words, the pump is discharging on both the extend and retract strokes of the driving cylinder.

Figure 4.2 illustrates a double-acting pump. As one plunger retracts from the valve boxes, material is drawn into the pump chamber; as the opposing plunger simultaneously extends toward the valve boxes, material is expelled from the pump chamber and sent on its way to the work site.

Because this pump operates on both the extend and retract strokes of the driver, there is no lost motion in which work is not being accomplished and grout sent to its destination. In addition, the solid plunger discharges a volume of material per stroke equal to its own volume, thereby making it a true "positive displacement" pump with an efficiency factor of approximately 90% to 95%.

Each of these pumps is actuated by either a pneumatic or hydraulic cylinder actuator, which cycles the pumping element (piston or plunger) in a continuous back-and-forth action.

Although each pump can often overlap in terms of performance characteristics, there is a reason for each to exist. The piston pump can be configured to pump large quantities of materials at moderate pressures, whereas the plunger pump will normally pump smaller quantities but at much higher pressures. In other words, each has its place in the grouter's toolbox.

In each case, discharge rates and pressures can be easily calculated.

Area calculation:

$$A = D^2 (\pi)/4 \text{ (or } A = r^2 \pi)$$

where:

A = End area of plunger or face area of piston
D = Diameter of piston or plunger (or r = radius)

Example: For a 3-inch-diameter piston: $3^2 \times 3.14/4 = 7.07$ in.^{2}

Discharge volume:

Using the same 3-inch-diameter piston, assume an 8-inch stroke for a single-acting pump:

7.068 in.^{2} × 8 in. = 56.544 in.^{3}/stroke
56.544 in.^{3} × 60 strokes/min = 3,392.64 in.^{3}/231 = 14.68 gpm
(Assuming 100% efficiency)

Discharge pressure:

$$P = A_1/A \times P_1$$

where:

P = Discharge pressure of pump
A_1 = Face area of driver piston
P_1 = Pressure of driving medium (air of hydraulic)

Example: If the area of a 6-inch-diameter driver piston is 28.27 in.^{2}, and the area of a 3-inch-diameter pump piston is 7.068 in.^{2}, and the driving medium (compressed air) pressure is 100 psi, then

$$\frac{28.27}{7.068} = 3.999 \times 100 = 399.9 \text{ psi}$$

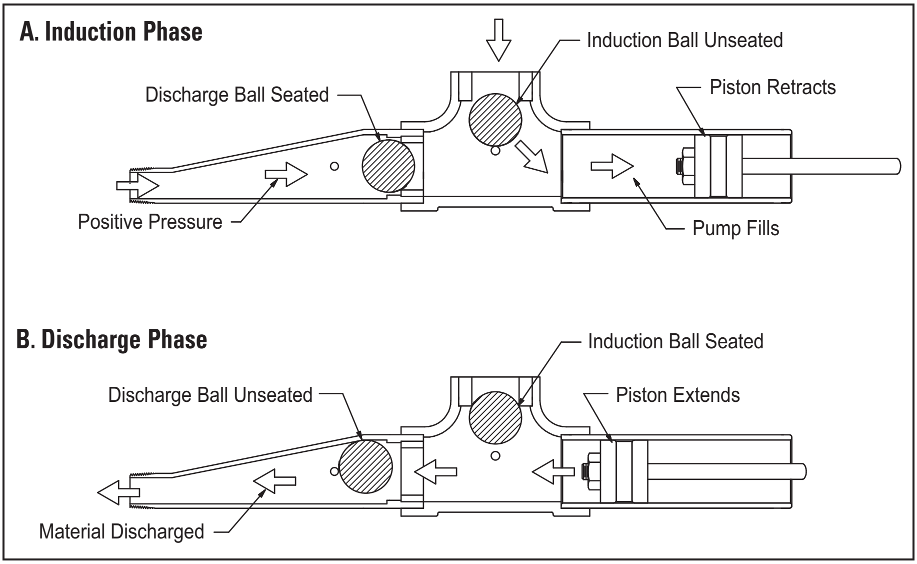


Figure 4.3 Simple ball valve action

Ball Valves

The ball valve illustrated in Figure 4.3 relies on the "floating ball principle" in which a ball fabricated of a material with a specific gravity less than the material being pumped actually floats on the material upon being unseated by either suction or pressure.

The valves of the plunger pump illustrated by Figure 4.4 operate on the "gravity ball principle" in which a very heavy ball, usually fabricated from iron or steel, seats as a result of gravity and is further aided by the pressure generated by the pump as material is expelled from it.

As can be seen in Figure 4.3, as the piston moves back, the inlet ball unseats while the discharge ball seats. As the piston moves forward, the discharge ball unseats and the inlet ball seats. The same kind of action takes place in the plunger pump, but with a somewhat different geometry, as illustrated by Figure 4.4.

In Figure 4.4, the pump is viewed "end on," and the valve chambers are located on either side of the pump. Figure 4.4a depicts the plunger moving away from the valves, thus inducing grout into the pumping chamber while the discharge valve ball is tightly seated by the higher pressure of material previously pumped. Figure 4.4b shows the plunger extending, thus forcing the material against the discharge valve ball and out of the pump. The resulting higher pressure within the pump body and valve chambers now tightly seats the induction valve ball, preventing material from migrating back into the hopper or mixing tank.

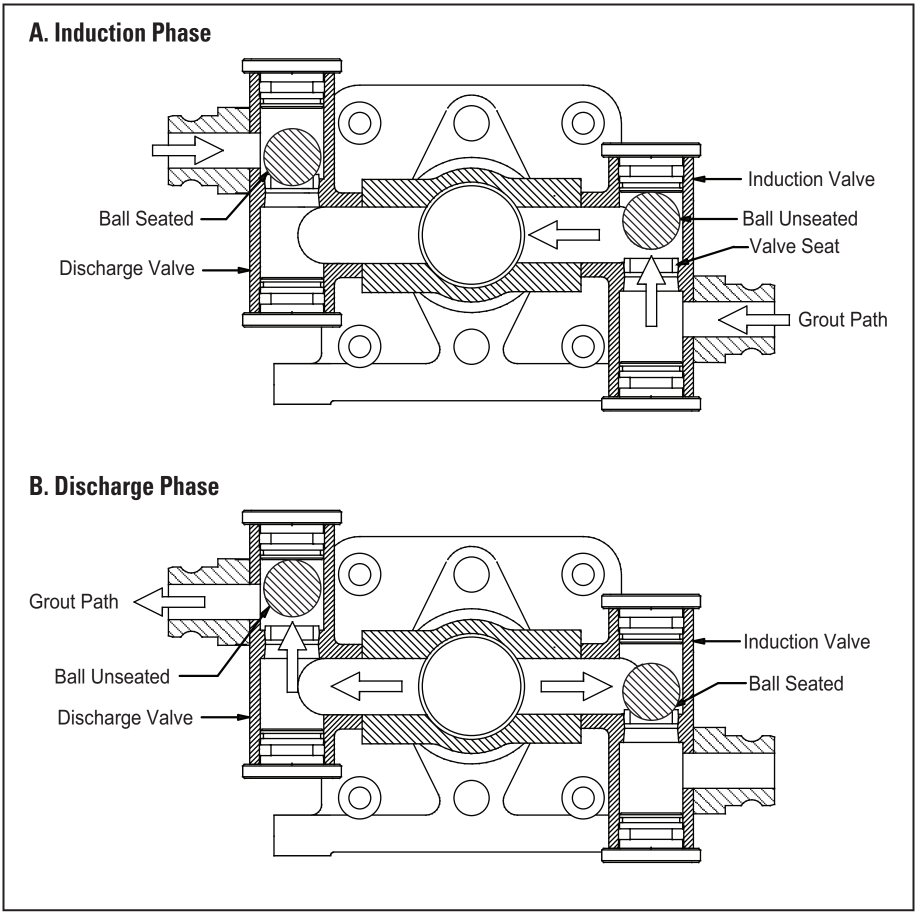


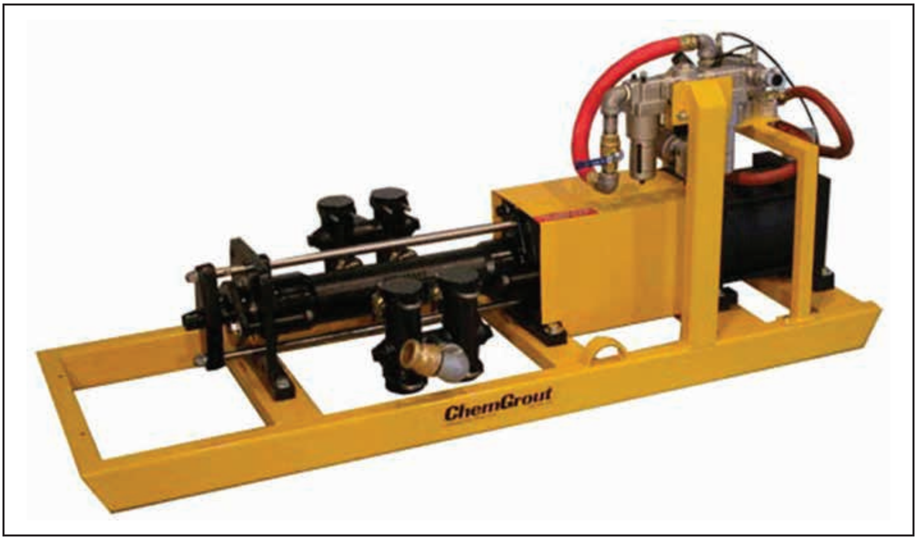
Figure 4.4 Double-acting ball valves

Figure 4.5 illustrates a double-acting plunger pump driven by a pneumatic cylinder. Figure 4.6 shows the same type of pump driven by a hydraulic cylinder powered by an onboard electric motor. Each photograph clearly shows all four valve boxes as depicted in Figure 4.4 and as previously described.

Figure 4.7 shows a pneumatically driven 2-inch piston pump. Piston pumps do not necessarily need any specific type of power drive. Figure 4.8 shows a pump that is operated by hand. The operator stands on the base and operates the pump with a hand lever.

Relief Valves

When using reciprocating pumps with ball valves (or any type of positive closing valves), there should be a means provided in the grouting system of relieving process material pressure, and it should be as close to the pump as possible.



Courtesy of ChemGrout.

Figure 4.5 Pneumatically driven double-acting plunger pump

Courtesy of ChemGrout.

Figure 4.6 Electrically powered, hydraulically driven double-acting plunger pump

When the discharge valve closes, whatever pressure was exerted on the grout circuit by the pump is confined between the pump and the intended target of the material. Should there be some type of blockage preventing the unimpeded flow of grout, such as a sudden closure of the feature being grouted or a hose becoming clogged or kinked, excessive pressure will quickly build in the line. If this should happen, it could result in a dangerous condition in which a line could fail explosively, spraying grout and possibly causing injury to workers or observers.

Courtesy of Airplaco Equipment.

Figure 4.7 Pneumatically driven 2-inch piston pump

The best place to install a relief valve is directly on the discharge port or fitting of the pump. Should a blockage in the grout delivery system occur, opening the valve will relieve the pressure in the entire line, allowing the couplings to be opened safely for inspection and servicing. The grout pressure relief valve, when used properly, is a safe way to relieve the pressure before disconnecting the hose. Figure 4.9 illustrates where the relief valve should be located at the discharge port of the pump and Figure 4.10 is a closeup of a pressure relief valve.

Important safety measures for using a pressure relief valve include the following:

- Make sure there is no pressure in the line when disconnecting hose from pump discharge port.
- The relief port of the grout pressure relief value must always be placed down and away from the operator.

Courtesy of ChemGrout.

Figure 4.8 Manually operated 2-inch piston pump

Courtesy of ChemGrout.

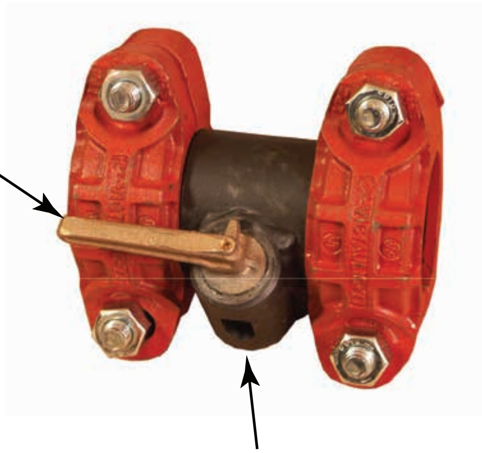
Figure 4.9 Relief valve at discharge end of 3-inch piston pump

Correct operation of a pressure relief valve includes the following maintenance procedures:

- The valve should be cleaned every day while cleaning the machine.
- After four or five usages, the relief valve should be disassembled and grease applied to the insides of the valve.

Timing

In order for piston and plunger pumps to reciprocate (i.e., change direction), there must be some built-in mechanism that allows the piston or plunger to change direction when it has reached its limit of travel on both the extend and retract strokes. This characteristic is often referred to as "timing" and can be accomplished in a variety of ways: (1) by direct mechanical linkage to a directional control valve; (2) by cam-actuated pneumatic or hydraulic pilot valves that, in turn, actuate directional control valves; (3) by proximity sensors operating electrically actuated directional control valves; and (4) by direct-acting self-reciprocating valves. Timing allows the valve to shift, as illustrated by the schematic diagram shown in Figure 4.11, and is used for pilot-actuated pneumatic cylinders.



Courtesy of ChemGrout.

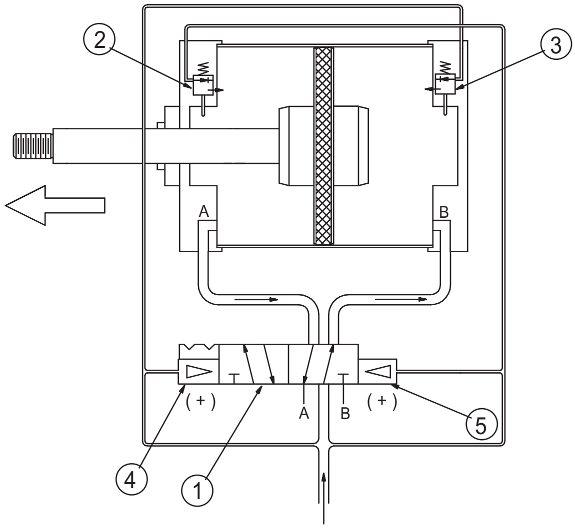
Figure 4.10 Pressure relief safety valve

Another timing method was employed by a class of reciprocating piston pumps known as steam pumps, so named because they were originally used to pump condensate and makeup water for large boilers, such as steamships and power plants, and were driven by steam rather than compressed air or other means. These pumps feature a timing valve that is integral with the driving cylinder, but because it is not possible to use either pilot valves or proximity sensors with steam, the timing valve is actuated by means of a mechanical linkage from the piston rod. As the rod extends and retracts, the linkage positions the valve to cause continuous reciprocation.

Although not often seen on grouting projects today, steam pumps have been driven by compressed air and used very successfully for a variety of grouting applications.

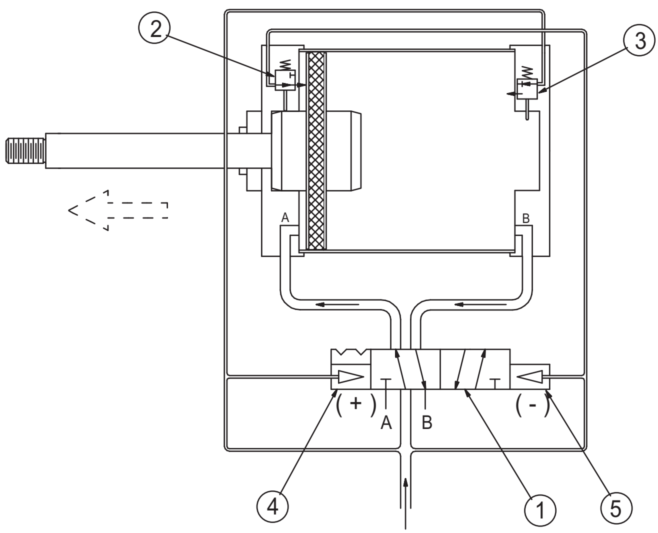
Figure 4.12 shows a reciprocating pump with integral directional control and pilot valves. Figure 4.13 is a double-acting plunger pump being driven by a pneumatic cylinder that is timed by means of the timing system illustrated by Figure 4.11. Figure 4.14 is an example of a dual plunger hydraulically driven pump that utilizes electric proximity sensors on each cylinder to produce an alternating reciprocation between the two cylinders.

(A)



The piston is traveling toward the extended position with the directional control valve (1) directing the compressed air supply through port B to drive the piston forward. Air pressure ahead of the piston is relieved through port A of the directional control valve. The valve spool is maintained in this position by positive air pressure at the pilot port (5).

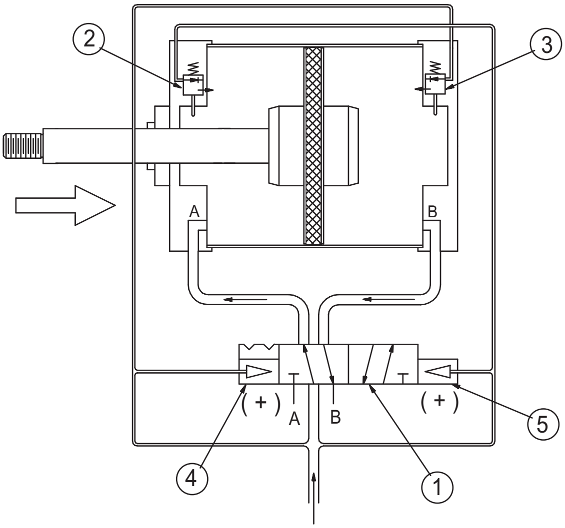
(B)



The piston has reached the limit of its extend travel and has actuated a pilot valve, thereby releasing sufficient air to cause an imbalance of the air pressure within the directional control valve.

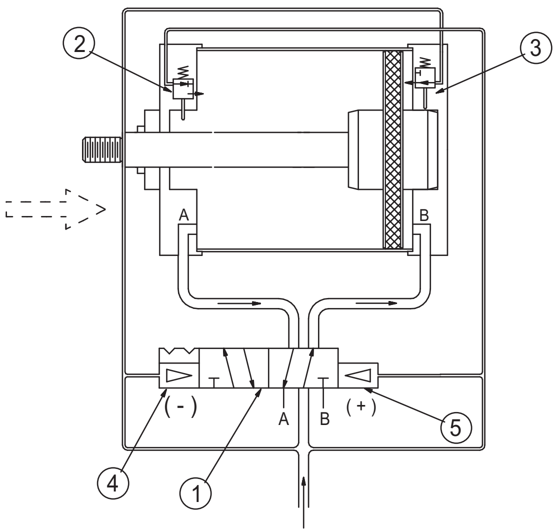
Figure 4.11 Timing sequence diagram for pilot-actuated pneumatic cylinders (figure continues)

(C)



The positive pressure is now directed to pilot port 4, thus causing the valve to shift, directing the air flow to port A, and causing the piston to reverse its direction.

(D)



The piston is fully retracted where it makes contact with the retract end pilot valve, thus completing the cycle to drive the piston forward again and thereby maintaining the automatic reciprocating action.

Figure 4.11 Timing sequence diagram for pilot-actuated pneumatic cylinders (continued)

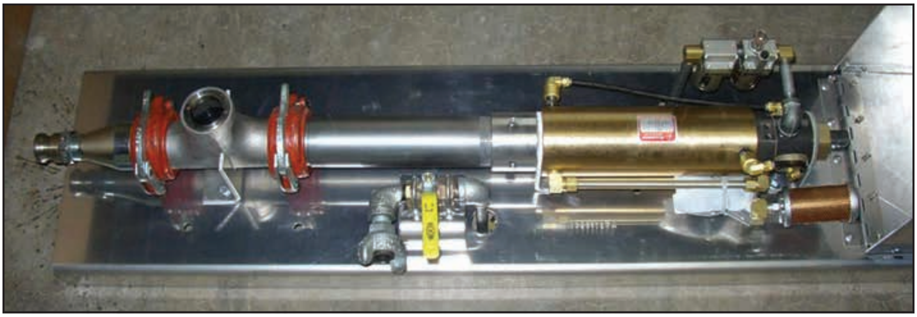
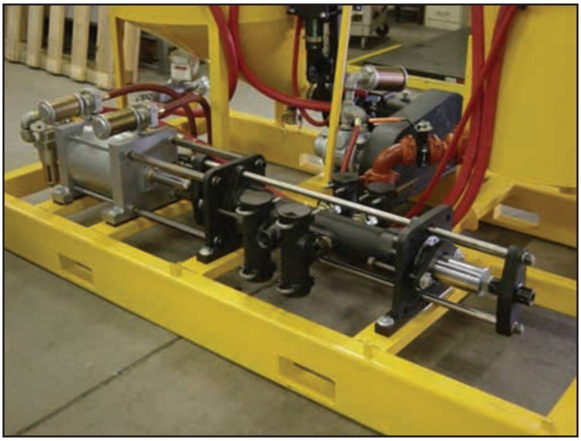


Figure 4.12 Reciprocating pump with integral directional control and pilot valves



Courtesy of ChemGrout.

Figure 4.13 Double-acting plunger pump driven by internally piloted pneumatic cylinder

A self-reciprocating valve also exists that does not require an external pilot (Figure 4.15). It receives the signal to change direction by means of internally detecting the hydraulic flow reduction that occurs at the end of each stroke and automatically reacts by changing the flow pattern to the device (cylinder), thus reversing its direction.

Piston Pump Maintenance and Repair

The procedures in this section are intended to be universal and applicable to piston pumps from any manufacturer. The only difference would be regarding details of assembly. Therefore, the instructions are somewhat general and will possibly lack the detail to be found in a manufacturer's owners manual. In addition, the procedures herein will relate only to the fluid end of the pump, neglecting the drive end. Figure 4.16 shows the parts pertinent to a typical grout pump. These piston pump repair procedures shown in Figure 4.17 are applicable to any piston-type grout pump. The troubleshooting guide

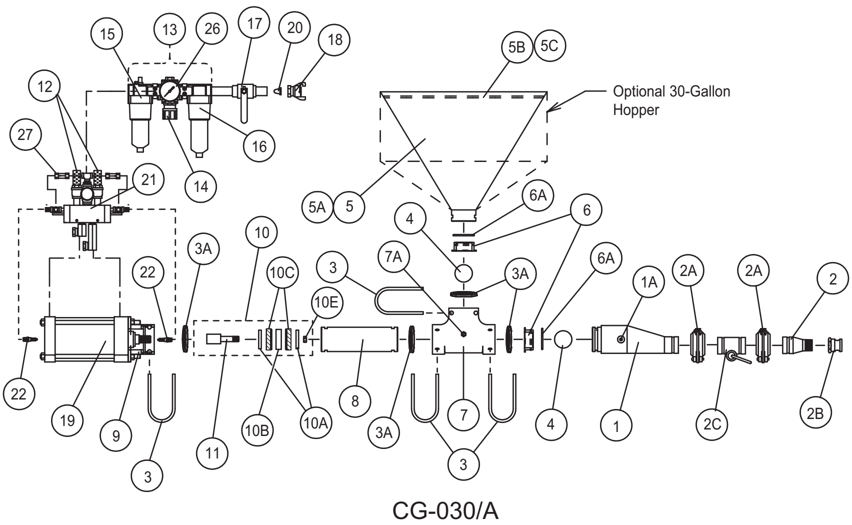
Courtesy of Häny AG.

Figure 4.14 Electrically timed duplex grout pump

shown in Table 4.1 is a good place to start when something does not look or feel right during operation of the pump, wherein repairs are contemplated.

The troubleshooting guide in Table 4.1 and the repair procedure shown in Figure 4.17 relate mainly to pumps that are driven by compressed air, although piston and plunger pumps are frequently hydraulically driven. Details of how reciprocating pumps are driven hydraulically are discussed in more detail in Chapter 6, Power Transmission.

Figure 4.15 Self-reciprocating hydraulic valve



1	Reducer *(3" × 2" Victaulic)*	10A	Piston Backer Plate
1A	Reducer Bolt *(3⁄8–16×3¼")*	10B	Piston Spacer Plate
2	2" Victaulic × 1¼" NPT (National Pipe Thread) Reducer	10C	Piston Cup
		10D	Nut
2A	2" Victaulic Coupling *(with gasket)*	11	Piston Adapter
2B	1¼" Part A Evertite Coupling	12	Exhaust Silencer
2C	Grout Pressure Relief Valve	13	1" Filter/Regular/Lubricator
3	Staple Pin	14	1" Regulator
3A	Pin Coupling Gasket	15	1" Lubricator
4	2⅝" Polyurethane Ball	16	1" Filter
5	15-Gallon Hopper	17	1" Ball Valve
5A	30-Gallon Hopper *(optional)*	18	1" Air King Fitting
5B	Screen for 15-Gallon Hopper	19	6" × 7" Air Cylinder
5C	Screen for 30-Gallon Hopper	20	30 Mesh Air Filter
6	Ball Seat	21	½" Pneumatic Directional Control Valve
6A	O-Ring for Ball Seat	22	Air Bleeder Valve *(directional control)*
7	Tee	23	Pressure Gauge
7A	Hopper Ball Retainer *(3⁄8–16×4½")*	24	⅛" Check Valve
8	Sleeve		
9	Air Cylinder Bracket		
10	Piston Assembly *(parts 10A to 11)*		

Source: ChemGrout 2012a.

Figure 4.16 Three-inch piston pump parts drawing

1. Disassemble the discharge end of the pump. Inspect and clean the parts, especially the discharge ball and ball seat. If the seat is grooved or worn, replace it. If the ball has nicks or grooves on its surface, replace it as well.
2. Disassemble suction (inlet) section of pump and perform the same inspection and cleaning procedure done in item 1. Replace worn parts.
3. Remove or disassemble the pump cylinder and inspect it for wear, pitting, scratches, or grooves. If grooves are not too deep, they may be removed by honing. If honing does not remove the grooves or pitting, replace the cylinder with a new part.
4. Remove the piston from the driving cylinder rod and disassemble, removing the piston seals (whether cups, O-rings, or U-cup seals), and replace them with new parts.
5. Having replaced all of the worn parts with new ones, reassemble the pump in reverse order, being careful not to damage the new parts during assembly.

Figure 4.17 Procedure for piston pump repair

Table 4.1 Troubleshooting guide for pump repair*

Problem	Probable Cause	Solution
Pumps water okay, but will not pump grout.	Grout mix too thick, does not enter pumping chamber.	Add sufficient water to make grout more fluid, but not so much as to be "soupy."
	Aggregate too large, prevents ball from seating.	Change to smaller aggregate or screen out large particles.
	Aggregate segregations in discharge hose.	Drain residual water from discharge hose prior to pumping grout, and lubricate discharge hose with slurry before pumping sanded grouts.
	Grout material has excessive coefficient of internal friction.	Some commercially prepared grout materials are not pumpable.
Pump stalls on discharge stroke.	Pump discharge or hose plugged with grout.	Disconnect discharge hose, then clean out hose and pump.
	Discharge hose kinked or obstructed.	Straighten hose or remove obstruction.
	Discharge valve improperly installed.	Remove U-clip, disassemble discharge end of pump, and check valve for proper installation.

(table continues)

Table 4.1 Troubleshooting guide for pump repair* (continued)

Problem	Probable Cause	Solution
Pump runs but does not discharge.	Grout not entering pump chamber.	Grout is too thick or inlet port is obstructed.
	Inlet valve installed incorrectly.	Remove hopper and check inlet valve. Ball should be below ball seat.
Piston "stutters" or does not reverse direction.†	Sluggish or inoperative pilot valve.	Determine by observation which pilot valve is faulty, then remove and clean or replace.
	Directional control valve not shifting properly.	Disassemble and clean with solvent.
Pump strokes unevenly or too slowly.†	Directional control valve not shifting properly.	Disassemble and clean with solvent.
Pump does not run.†	Insufficient air supply.	Check air source, including hoses and fittings.
	Pump fluid end plugged.	Disassemble pump discharge fittings and clean out.
	Air cylinder pilot valves inoperative.	Remove pilot valves and clean with solvent.
	Directional control valve not shifting properly.	Disassemble and clean with solvent.
Pump has low discharge rate.	Low air pressure or volume.	Check air source. A 2-inch pump requires 10 cfm at 100 psi. A 3-inch pump requires 15 cfm at 100 psi.
Material leaks from rear end of pump.	Worn piston seals.	Replace piston seals.
Pump will not maintain fluid pressure.	Worn piston seals.	Replace piston seals.
	Worn valve seats.	Replace valve seats.
Material bubbles back into hopper.	Worn intake valve seats.	Replace valve seats.

Source: ChemGrout 2012a.
*This table coincides with the part numbers in Figure 4.16.
†To isolate whether the problem is faulty pilot valves or a faulty directional control valve, remove the hoses from the pilot valves, hold one in your left hand and the other in your right in such a way that you can cover the ends with your thumbs. Turn on the air. If you can cycle the pump by covering the hose ends alternately with your thumbs, your directional control is functioning properly, and the problem is most likely in the pilot valves.

Plunger Pump Maintenance and Repair

For this discussion, it is assumed that the plunger pumps being repaired are driven pneumatically (as frequently they are). Most of the problems likely to be encountered with a piston pump can also be experienced with a pneumatically driven plunger pump, which means that the symptoms and cures listed in Table 4.1 will also apply to plunger pumps except that there is much less maintenance required on plunger pumps than piston pumps.

Although their design is not much different from piston pumps in that similar components are wear items that need to be replaced periodically, plunger pumps are much easier to maintain. The plunger never touches the wall of the pumping chamber (cylinder), thus there are no scratches or gouges to be removed.

The plunger seals are mounted outside the pumping chamber; therefore, it is not necessary to disassemble the pump to change them. The only items that need to come apart are the valve boxes, and even then, it may be possible to accomplish repairs to some pumps with only minimal access. Typical parts for a plunger pump are shown in Figure 4.18.

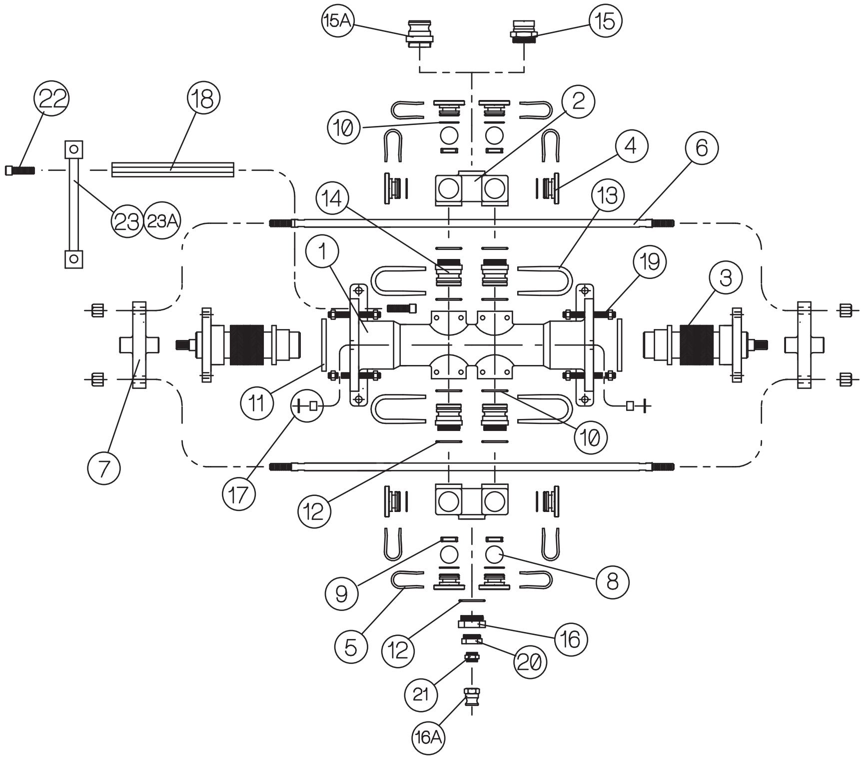
The double-acting plunger pump described in Figure 4.18 features interchangeable plungers of four diameters for the purpose of changing delivery pressures and volumes for specific project requirements.

ROTARY PUMPS

The rotary type pumps most likely to be encountered on a variety of grouting projects are *progressing cavity pumps*, often called "Moyno" pumps in the United States (Figure 4.19). Moyno is the registered brand name of the progressing cavity pumps manufactured since 1936 by Robbins & Myers Company. It is the U.S. version of the pump invented by Rene Moineau in 1930 and manufactured since 1932 by PCM Pompe in France. Progressing cavity pumps are now made by many manufacturers, including Allweiler, ChemGrout, Netzsch, Putzmeister, Roper, Strong, and Tarby. They are also sometimes called "screw pumps," "worm pumps," and "snake pumps" in reference to the rotor design.

This type of pump is particularly useful in applications where the pulsation inherent in most reciprocating pumps is intolerable or undesirable, such as spray applications of repair mortars and some kinds of foundation grouting. Indeed, these pumps have been specified for use in dam foundation grouting by the U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation for many years.

In its basic form, the progressing cavity pump consists of a helical rotor of uniform cross section rotating within a mating dual helix stator, usually constructed from some kind of elastomer, such as nitrile rubber, natural rubber, or some other substance, and encased within a tubular steel outer casing (Figure 4.20). As the rotor rotates, it causes cavities to open and close, propelling the process material along the length of the stator until it is expelled from the discharge fitting. The stator is attached to and supported by a suction housing that serves as the process material induction port, and the rotor is connected to a drive shaft and bearing assembly through which a driving force is imparted to the rotor by means of a motor or other driving device.



1	Pump Body	15	Suction Coupling
2	Valve Box *(2 required)*	15A	Alternate Suction Coupling
3	3" Plunger Group	16	Suction/Discharge Fitting
4	Valve Box Cap *(8 required)*	16A	Discharge Fitting *(optional)*
5	Valve Cap Key *(8 required)*	17	Traverse Rod Bushing and Retainer
6	Traverse Rod *(2 required)*	18	Spacer Bar *(4 required)*
7	Yoke *(2 required)*	19	Packing Gland Bolt *(4 required)*
8	Valve Ball *(4 required)*	20	1¼" × 1" Hydraulic Bushing
9	Valve Seat *(4 required)*	21	1" Hydraulic Nipple
10	Valve Cap O-Ring *(12 required)*	22	Socket Head Cap Screw *(4 required for air powered; 8 required for hydraulic powered)*
11	Pump Body Ring *(2 required)*	23	Hydraulic Cylinder Mounting Plate for All Except 3½" Plunger
12	Connector O-Ring *(5 required)*	23A	Hydraulic Cylinder Mounting Plate for 3½" plunger
13	Connector Retaining Staple *(4 required)*		
14	Valve Box Connector *(4 required)*		

Source: ChemGrout 2012b.

Figure 4.18 Double-acting plunger pump parts drawing

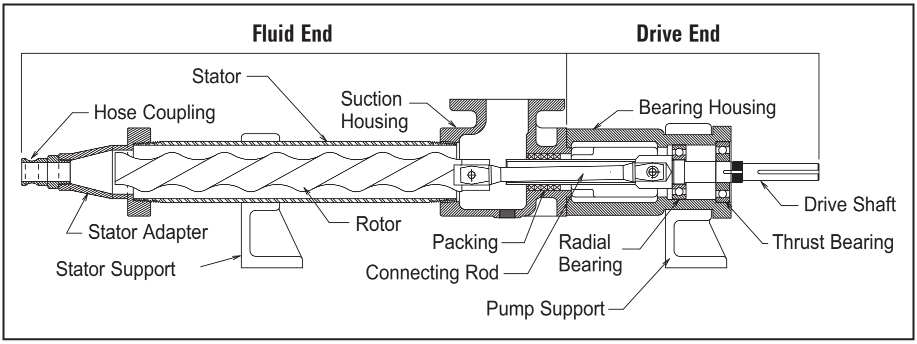


Figure 4.19 Progressing cavity pump construction features

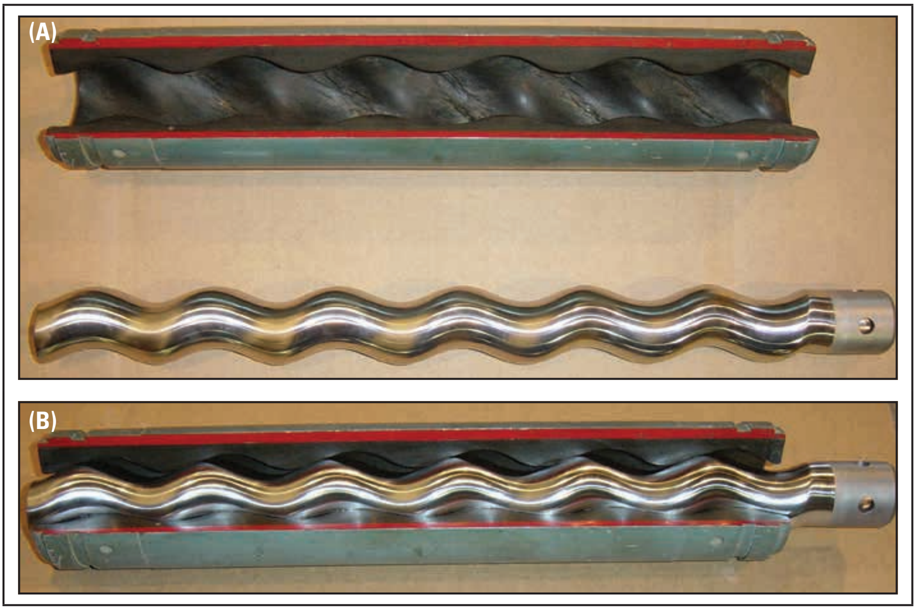


Figure 4.20 Rotor and stator: (a) separate and (b) assembled

Progressing cavity pumps are available in a variety of sizes and configured as either "open throat" or "closed throat" versions. Open-throat pumps, as depicted in Figure 4.21a, are characterized by a large, rectangular induction opening directly on the top of the suction housing. Closed-throat pumps, as illustrated in Figure 4.21b, will generally have a round, flanged induction fitting intended to be mechanically connected to the source of the process material, which is usually an agitator.

The *discharge rate* of a progressing cavity pump is governed by two factors: the *size* of the pump (expressed as a reference number that seems to have no relationship to any

Figure 4.21 Progressing cavity pumps: (a) open throat and (b) closed throat

standard dimensional measurement) and the *speed of rotation*. The faster the rotation, the greater the discharge rate; and the larger the pump, the greater the discharge rate for any speed of rotation. *Discharge pressure* is determined by the *number of "stages"* of the rotor and stator elements, or more simply, by the length of the rotor and stator. More length equals greater pressure, up to a point. The practical limit is approximately 722 psi, which is the pressure developed by nine stages.

Construction features vary between manufacturers and within different models from the same manufacturer, but pumps most frequently used for grouting service are derivations of the original PCM Moineau (Moyno) pump industrial design. These are known generically as pin joint pumps, which describes the method of joining the internal rotational components. These joints are designed to accommodate the elliptical motion of the rotor as it rotates within the stator, allowing it to move laterally as well as rotationally. Other types of internal joints continue to be used, but since these parts are subject to immersion within the relatively abrasive process material (grout), and since portland cement products tend to harden if not thoroughly cleaned from inside the pump, the pin joint seems to be the most dependable, as it is relatively trouble free and easily maintained.

Although it is possible to run some of these pumps at rotational speeds of up to 1,000 rpm, experience and experimentation have dictated that the best stator wear can be obtained by limiting pump speed to about 300–400 rpm when pumping abrasive materials, such as portland cement–based grouts. When run at this speed, little difference in wear characteristics have been noted, whether pumping slurry mixes or sanded mixes. These pumps are designed to handle thick and abrasive materials, but they must be treated with respect to get the best service life from them.

Model Numbers

To those unfamiliar with the terms used to describe the features of these pumps, the model numbers can be an undecipherable alphabet soup of numbers and letters; however, they do mean something, and once you "crack the code," it makes a lot of sense.

The nomenclature system used in the United States was originated by Robbins & Myers to describe the Moyno series of pumps, and it has been recognized and almost universally accepted by other manufacturers since. A pump frequently used on grouting jobs is a Moyno (or Tarby, or ChemGrout, or Strong) Model 3L6CDQ. This model number can be deciphered as shown in Figure 4.22.

The electrically powered, hydraulically driven pump in Figure 4.23 is a Model 3L10CDQ. Deciphering the code with the example data given in Figure 4.22, this means it is a pump with three stages, a closed throat, size 10, with cast-iron exterior, carbon steel inner parts, and nitrile rubber stator elastomer. It is easy when you can read the code.

Maintenance and Repair

This section will illustrate and describe the most common repair procedures that are performed on progressing cavity pumps. These illustrated step-by-step procedures are intended to guide the operator or mechanic through the repair procedure, thus eliminating the trial-and-error process that is often employed.

Drive Shaft Packing

It is always best to keep pumps as clean as possible, both during production and at the end of each shift. One of the things the operator will be looking for on a daily basis is evidence of material leakage from the packing that forms the seal around the drive shaft. Often, when

<u>3</u>L6CDQ	The first number is the number of stages, which can be any number from 1 to 9.
3**<u>L</u>**6CDQ	The first number is generally followed by a letter. In this case, the letter L means it is a standard closed-throat pump. Letters are defined as follows: C = Open-throat pump converted from what was originally a closed-throat pump J = Open-throat pump, original Moyno configuration with grooved stator clamp L = Closed-throat pump M = Closed-throat pump with four to six stages; has drive end from the next larger size pump P = Closed-throat pump with up to nine stages; has drive end that is two sizes larger TJ = Open-throat pump with threaded stator TL = Closed-throat pump with threaded stator (usually manufactured by Tarby)
3L**<u>6</u>**CDQ	The next number is the size of the pump. In grouting work, one will rarely see anything smaller than size 4, and occasionally pumps will run as large as size 10 or size 12. The most popular for grouting applications are sizes 6 and 8. These sizes relate to maximum capacity in terms of gallons per minute, as follows: Size 4 = 25 gpm Size 6 = 50 gpm Size 8 = 100 gpm Size 10 = 150 gpm Size 12 = 200 gpm
3L6**<u>CDQ</u>**	The last three letters refer to the materials of construction. The first letter designates the exterior material (or castings), the second letter designates the material from which the internal parts are made, and the third letter is the stator material: A = Cast Aluminum C = Cast Iron D = Carbon Steel Q = Buna N Nitrile Rubber R = Natural Rubber S = Stainless Steel T = Viton

In this example, Model 3L6CDQ is a three-stage closed-throat pump, size 6, with a cast-iron exterior, carbon steel internal parts, and a nitrile rubber stator elastomer. Since this pump uses a Buna N stator elastomer (Q), it will develop at least 261 psi (87 psi per stage).

Figure 4.22 Example of model number nomenclature

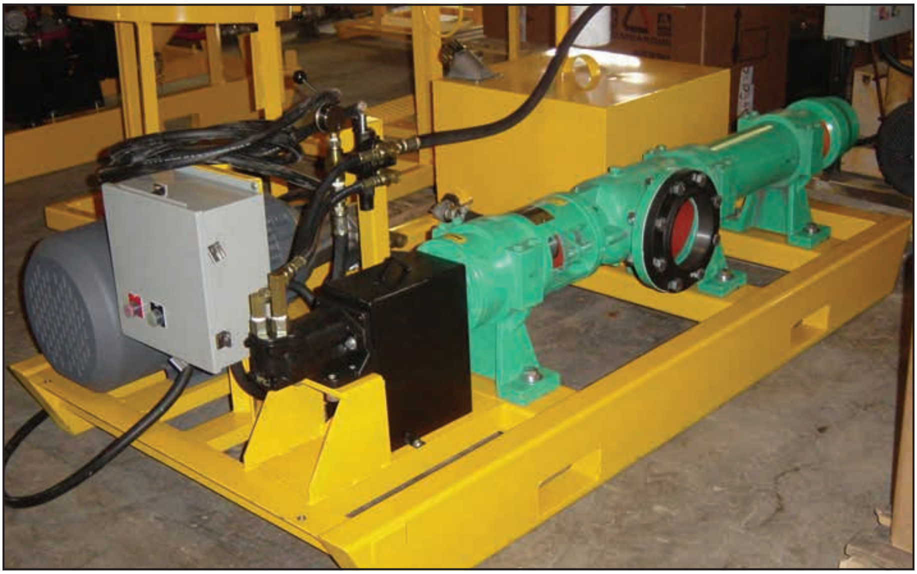


Figure 4.23 Electrically powered, hydraulically driven 3L10CDQ pump

such leakage is noted, a shot or two of grease in the stuffing box grease fittings, as illustrated in Figure 4.24a, is all that is needed. If leakage persists, then it may be necessary to tighten the nuts on the packing gland, as shown in Figure 4.24b. They should be tightened only a little on each side to keep the gland seated squarely on the packing and tightened only until the leakage has stopped. If the nuts are tightened as far as the studs will allow, it is time to back them off the packing gland and add another piece (or two) of packing.

Grout may eventually infiltrate the packing. When this happens, no matter how tight the packing gland is tightened, it will still leak. When this occurs, it is time to remove and replace all of the packing.

WARNING: If leakage is allowed to persist over an extended period of time, grooves will be worn in the drive shaft; at this point, no amount of packing will stop the leakage, and the drive shaft will have to be replaced.

Dedicated packing removal tools (Figure 4.25) are available at most industrial hardware outlets, but picks, awls, and other tools have been successfully used to remove old packing. When removing old packing, the lantern ring must also be removed to get to the packing ahead of the lantern ring. In the size 2L4 pump shown in Figure 4.25, there are two rings of packing ahead of the lantern ring and four rings between the lantern ring and the packing gland. When inserting the new packing rings, it is important to "stagger" the joints to prevent leakage.

These pumps seldom fail catastrophically; that is, there are generally warning signs that something destructive is about to happen. For example, if the pump is driven through

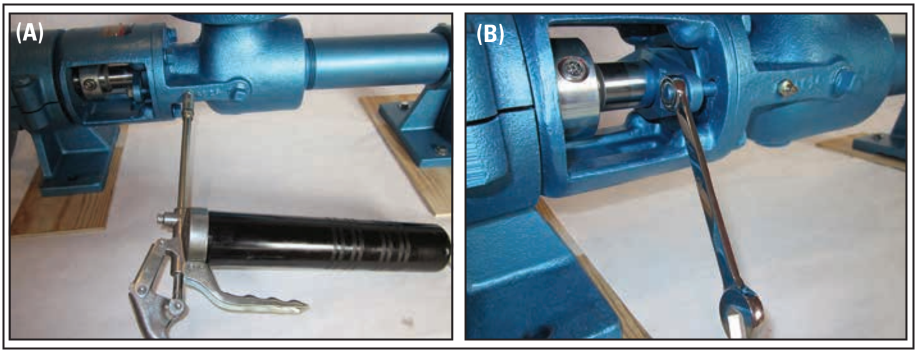


Figure 4.24 (a) Grease applied to the packing and (b) tightening the packing gland

sheaves and belts, and the operator notices that the drive sheave will turn 5 or 10 degrees before the resistance of the rotor and stator assembly is felt, there is a good chance that the joint pins are worn and will soon fail. This should be dealt with immediately, because it is one of the few causes of catastrophic pump failure.

Rotor and Stator

One of the ongoing maintenance items that needs to be monitored from time to time is the condition of the rotor and stator. In general, a rotor will usually outlast the stator by a factor of two to one; that is, a stator will have to be changed twice before a rotor needs replacing. However, this depends on the materials being pumped; if only slurry mixes are pumped, it may be possible to change three stators to one rotor. However, if a lot of heavily sanded material is being pumped, the two-stators-to-one-rotor equation may not hold true, but there are ways to make this a lot less uncomfortable in terms of economics. If the need is to pump a lot of heavily sanded materials, a hardened steel rotor and a natural rubber stator can be obtained; this combination will last much longer than the standard materials. Equipment suppliers can be queried about this option.

In the meantime, how does an operator know when it is time to change a stator? Certainly, it is time to change when the material he or she is attempting to pump no longer comes out the end of the hose, but normal maintenance should not be delayed to this point. A good procedure to determine the health of a rotor and stator is to periodically run a pressure test with water. Figure 4.26 illustrates this procedure. The pump is fitted with a bypass return hose, a shutoff valve, and

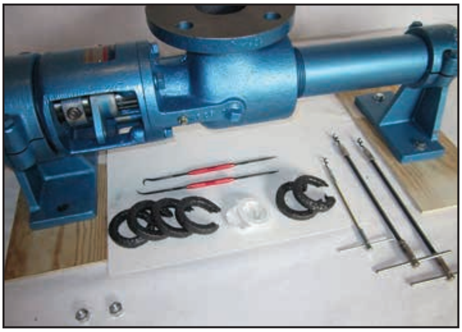


Figure 4.25 Packing tools and new packing set

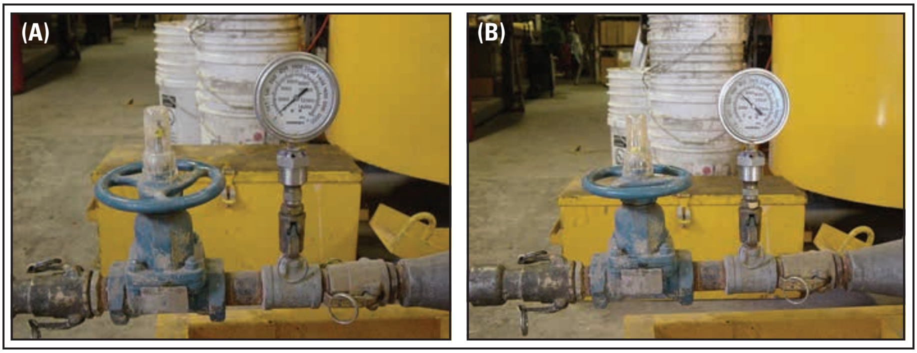


Figure 4.26 Water pressure test: (a) valve open and (b) valve closed

a pressure gauge. Figure 4.26a shows the pump circulating water with the valve opened; Figure 4.26b shows the pressure generated by the pump with the valve closed. A good habit is to perform this procedure at least once a week and record the results. This reveals a lot, not only about the condition of the pump, but it may possibly suggest ways to improve the application.

When the water test pressure drops below an acceptable range for the work required, then it is time to change the stator. As previously mentioned, a stator made with 70 durometer nitrile rubber elastomer should produce at least 87 psi per stage, so that should be the initial target value. However, new stators often produce much more pressure than that. For example, the pump shown in Figure 4.26b is a three-stage pump with a new stator that is expected to produce 261 psi; the gauge shows 620 psi. Although this is a little unusual, twice the rated value is often seen with a new rotor and stator.

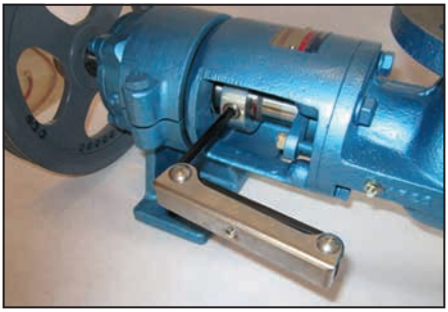
Eventually, the time will come for a stator change, and although this may seem to be a daunting task, it can be made much easier by following the step-by-step instructions given in Figure 4.27. This procedure works for all domestic pin joint pumps; the procedure for pumps of foreign manufacture may be slightly different.

The stator changing procedure is easy enough to do, so a good protocol to follow is dismantling the pump every few days that it is in constant production to facilitate a thorough cleaning. Of course, it will not be necessary to remove the rotor from the stator each time, but disconnecting the drive components from time to time ensures that it can be done easily when it becomes necessary to disassemble for maintenance or repair. In addition, this procedure makes it possible to clean materials from the pump in the event that power is lost for any reason and the pump cannot be turned on for normal flushing.

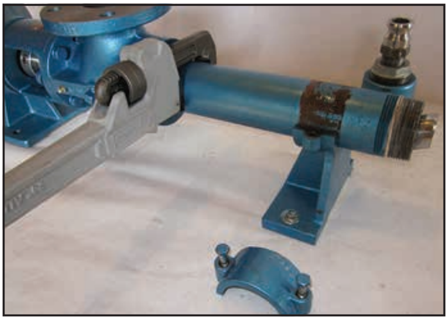
Bearings and Drive Shaft

The bearings of progressing cavity pumps, regardless of manufacture, are extraordinarily robust, and, under normal circumstances, should last the life of the pump. But sometimes circumstances require their removal from the pump, such as, for example, a badly scored

A. Remove the reducer.



B. Remove shaft pin retaining screws and shaft pin.



C. Unthread the stator.

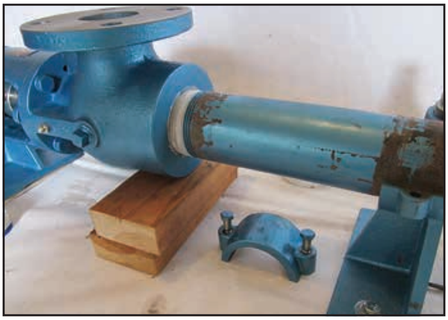
D. Stator removed with rotor and connecting rod.

1. Remove the discharge reducer (Figure A) from the discharge end of the stator. If threaded, use an appropriately sized pipe wrench or chain wrench to remove it. If clamped, remove the clamp bolts and clamp.
2. Moving to the drive end of the pump, remove the shaft pin retaining screws and washers from the shaft collar if a closed-throat pump, or slide the rubber pin retainer free of the shaft pin if an open-throat pump (Figure B). In both cases, drive out and remove the shaft pin.
3. Remove the stator support cap(s) and if the stator is threaded, unthread the stator from the suction housing (Figure C). If clamped, remove the clamp bolts and clamp.
4. When free of the suction housing, it should be possible to remove the rotor/stator assembly as a unit, including the connecting rod if it is a closed-throat pump or the conveyor tube and intermediate drive shaft if it is an open-throat pump (Figure D).

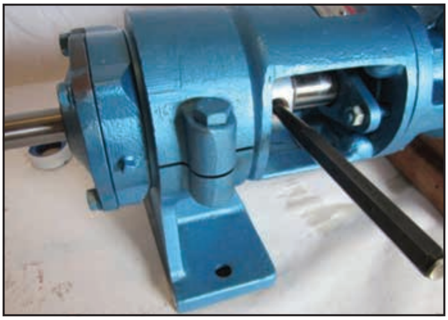
Figure 4.27 Procedure for changing a stator (figure continues)

E. Remove rotor from stator.

F. Insert rotor into new stator.



G. Reinstall stator to suction housing.

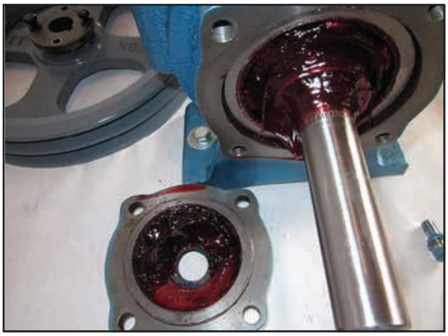


H. Align the shaft pin holes.

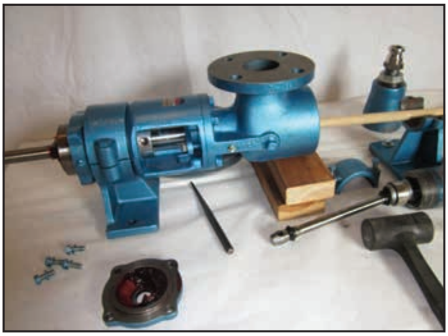
2. Lock the stator firmly in a vise, then rotate the rotor in a *clockwise* direction while simultaneously pulling on it to free the rotor from the stator (Figure E).
3. Lock the new stator in a vise and, having lubricated the rotor with hand soap or dish detergent, insert it into the new stator while rotating it in a *counterclockwise* direction and pushing it in (Figure F). Install the rotor slightly deeper into the new stator than it was in the original stator. This will make it easier to engage the threads when attaching the stator to the suction housing.
4. Grease the connecting rod end with lithium-based grease and reinstall the stator on the suction housing (Figure G), but only engage sufficient thread to ensure that it is properly started.
5. Returning to the drive end, align the connecting rod or intermediate drive shaft such that the drive pin can be inserted. This may require rotating the stator and rotor slightly to align the holes or tapping the end of the rotor with a soft metal bar and a hammer to drive it deeper, if necessary (Figure H). Using a tapered drift pin will help align the pin holes.
6. Replace the drive pin and pin retainer (or retaining screws and washers) and perform steps 1, 2, and 3 in reverse order of disassembly. The pump is now ready to return to service, and it has taken less than an hour to accomplish.

CAUTION: If your grouting procedure requires the use of polymer-modified materials or epoxy grouts, and particularly if you'll be using a closed-throat pump for that purpose, you should perform this procedure after every production shift.

Figure 4.27 Procedure for changing a stator (continued)



A. End plate/bearing retainer removed.



B. Bearings and drive shaft being removed.

C. Drive shaft with radial and thrust bearings.

1. Remove the end plate/bearing retainer from the drive end of the pump (Figure A).
2. Remove the drive shaft and bearings by means of a wooden dowel rod or a soft metal bar and a dead-blow hammer (Figure B). They should come out fairly easily.
3. After the drive shaft has been removed (Figure C), clean off lithium-based grease and remove the bearings from the drive shaft, either with an arbor press, if available, or by using a bearing puller.
4. Complete the repair by pressing either the original bearings or new bearings onto a new drive shaft. It is not likely that original bearings would need to be replaced nor new bearings installed on an existing drive shaft. Re-grease the bearings with lithium-based grease and reinstall the new drive shaft and bearings back into the bearing housing and replace the end cap/bearing retainer.

Figure 4.28 Procedure for replacing bearings and drive shaft

drive shaft or grout infiltration into the bearing housing. Removing the bearings and drive shaft is a fairly simple procedure involving the steps shown in Figure 4.28.

A handy way to keep the packing seals lubricated on any rotary pump, including the progressing cavity pump, is to use an automatic greaser like the one shown in Figure 4.29. One of the existing grease zerks in the suction housing is removed and replaced with

the automatic greaser. Grease is then injected into the case of the greaser via the zerk fitting provided for that purpose. As the grease enters the case, it compresses a spring behind a plunger that provides pressure to expel the grease as needed. The case is of clear plastic so that the quantity of grease in the case can be monitored and refilled as required.

Figure 4.29 Automatic greaser

Centrifugal Pumps

Other types of rotary pumps likely to be encountered on grouting equipment are the mixing pumps and colloidal mills on colloidal mixers. These pumps are discussed in Chapter 3, Mixers.

REFERENCES

ChemGrout, Inc. 2012a. *CG-550/030/A Operating and Maintenance Manual.* La Grange Park, IL: ChemGrout.

ChemGrout, Inc. 2012b. *CG-600/3X8/A Operating and Maintenance Manual.* La Grange Park, IL: ChemGrout.

5
Power Options

Many options are available for powering grouting equipment, and the best choice depends on several factors, including whether the machine is purchased for a specific application or will be used on many different applications. If it is intended for a single application, a tunneling project for example, the machine may be powered by the most available power source. Often for underground work, sufficient compressed air is available for drilling and other activities that the grout machine can also be powered pneumatically, although in other circumstances it would be the least efficient means of motivation. Thus, consideration of power options is very important. In this chapter, each of the possibilities are examined, and the advantages and disadvantages of each are noted.

ELECTRICALLY POWERED EQUIPMENT

Since an electric motor draws only enough power to perform the work required of it, electricity is, by far, the best and most efficient power choice for grouting equipment. However, it is only efficient if there is direct access to an adequate source of power; either 220 VAC (volts, alternating current) single-phase or 480 VAC three-phase power. If the power grid cannot be directly accessed and a portable generator must be relied on, then the electric energy advantage evaporates, and the equipment becomes not much more efficient than using pneumatic power.

Two types of electric motors are employed on commercially available grouting equipment: motors that operate on single-phase alternating current and those that function on three-phase alternating current. The most common source of electric power in North America is the three-conductor single-phase system consisting of two live conductors and a neutral conductor and which is distributed at 60 alternating cycles per second (60 Hz). This is the power source commonly distributed to residences and small commercial and industrial buildings, and typically results in voltages of 220/110, 230/115, or 240/120 depending on the age of the distribution grid and other factors, such as transformer ratios.

The second most common power source is provided by a four-conductor three-phase system in which three of the conductors are live and one is neutral. The characteristics

Courtesy of Häny AG.

Figure 5.1 Grout machine powered by individual electric motors

of three-phase power is that the alternating current is generated with each of the phases 120 degrees apart to provide three separate sine waves 60 times per second instead of just one as in the single phase system previously described. With three-phase electric power, typical voltages may be 440/220, 460/230 or 480/240, again depending on distribution grid characteristics. Three-phase power is usually only available to industrial plants and large construction sites.

European power transmission schemes are similar to North American power grids in that they also have access to single-phase and three-phase power; however, the voltages may be different. Most, if not all, commercially available grouting equipment has taken these differences into account, so equipment powered by electric motors will run well on either side of the Atlantic. However, equipment manufactured in the United States or Canada will operate at 5/6 the speed on Europe's 50-Hz power grid as they do in North America. Conversely, equipment manufactured in Europe will run faster on North American 60-Hz transmission systems than in the country of origin. The only change in motor design for use in some European countries would be additional stator windings to accommodate different standard voltages (e.g., 318 or 400 VAC).

Courtesy of ChemGrout.

Figure 5.2 Electrically powered, hydraulically driven grout machine

Unless separate motor controllers that allow adjustment of electric motor speeds are employed, equipment functions powered directly by electric motors will generally operate at only a single speed and are therefore limited in flexibility of purpose. Although many manufacturers power each function of the grout machine with individual electric motors (such as illustrated in Figure 5.1), a much more efficient method is to use a single motor to power a hydraulic system to distribute power to each of the machine functions. This method takes full advantage of the electric power efficiency while also allowing full control of each machine function with respect to speed and power. This is known as electrically powered, hydraulically driven and is illustrated in Figure 5.2.

The machine illustrated in Figure 5.2 has the power unit integral with the machine; that is, the electric motor, motor controls, and all of the hydraulic components, including the oil reservoir, pump, valves, and so forth, are all mounted on the machine frame. Sometimes, it is advantageous to separate the power unit from the machine. Such an arrangement offers several advantages: the power unit is removed from the dusty environment of the grout plant, the operator is removed from the heat and noise generated by the power unit, and the grout machine can be of a more compact design. Another advantage to this arrangement is that the grout machine is independent of its power unit so that if

Courtesy of Atlas Copco Craelius.

Figure 5.3 Two-piece grout plant with separate diesel power unit

electricity is not available, an alternative power unit, such as one driven by a gasoline or diesel engine, may be substituted, as illustrated in Figure 5.3.

Maintenance and Repair

Electric motors used on grouting equipment are not generally prone to problems, but if a motor should require replacement, whether single-phase or three-phase, the most important point is that, for safety reasons, NEVER replace a grout machine motor with an open electric motor.

The only type of electric motor that should ever be used on a grout plant is a TEFC (totally enclosed, fan-cooled) motor. Water will be used for mixing as well as for wash-down, and water and electricity can be a deadly combination. TEFC motors are enclosed and insulated against water intrusion, whereas open motors are not. In any case, when installing a new motor, make sure it is properly grounded.

If there is a problem with an electrically powered machine, the problem is more likely to be in the motor control module than in the motor itself. In this case, the manufacturer's maintenance manual should be consulted for a troubleshooting guide and repair procedures.

ENGINE-POWERED EQUIPMENT

A grout machine may be manufactured with an electric/hydraulic power unit for use when sufficient electric power is available and an alternate power source, such as a diesel or gasoline/hydraulic power unit or a piece of existing equipment such as a tractor or excavator with onboard hydraulics. This is particularly useful when operating on remote sites

Courtesy of ChemGrout.

Figure 5.4 Grout plant with integral diesel power unit

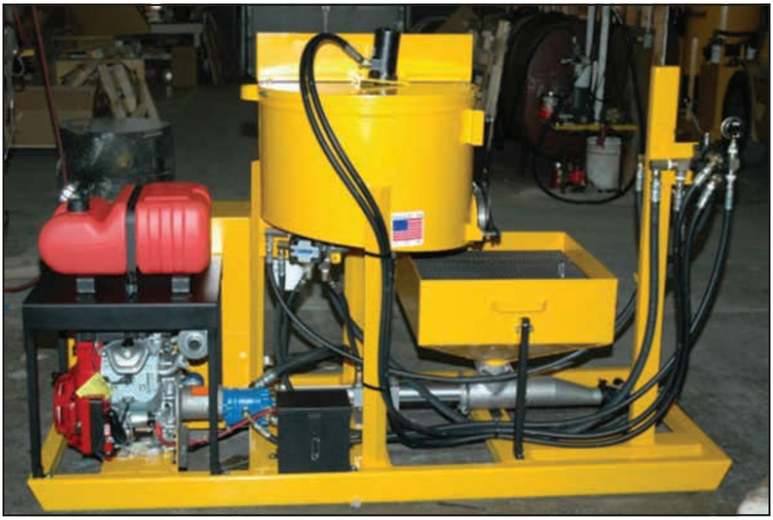
where access is difficult and electric power is not available. Skid steer tractors (Bobcats) often have auxiliary hydraulic ports that have been successfully used to power grout machines.

In addition, it is also possible to incorporate a diesel/hydraulic power unit on board the grout machine itself. Figure 5.4 shows a hydraulically driven machine with an onboard diesel/hydraulic power unit.

Gasoline engines are used to power smaller portable grout machines (Figure 5.5) but are no longer used on the larger colloidal machines since about the mid-1980s when the use of diesel engines had become economically feasible. Before that, large six- or eight-cylinder gasoline engines were used to generate the horsepower required to operate a colloidal grout machine, and these normally aspirated, carburetor-fed engines were not very fuel efficient. Of course, gasoline was not as expensive then as it is now, so fuel efficiency was not of great concern. Diesel engines, on the other hand, are very fuel efficient in addition to possessing power characteristics that make them ideal power plants for grouting equipment. Nevertheless, some smaller, less expensive equipment is still powered by gasoline engines in part because of the lower purchase price of gasoline engines over diesel engines.

PNEUMATICALLY POWERED EQUIPMENT

In terms of overall power usage, pneumatically powered equipment is the least efficient. The vane-type air motors most frequently employed on most grouting machines require enormous volumes of compressed air to the extent that even the simplest units will need a minimum of 175 cfm (cubic feet per minute) of compressed air at a pressure of up to



Courtesy of ChemGrout.

Figure 5.5 Small gasoline-powered grout machine

100 psi. This means that an operator will be running at least a 40-hp compressor to do a relatively modest amount of work, which is inefficient. Even so, there are good reasons for using a pneumatically driven grout plant.

First, if an operator happens to be working underground in a mine or tunnel, chances are good that plenty of compressed air is available for other purposes, such as running rock drills and various types of equipment. Furthermore, since the air used for the motors is simply expelled into the atmosphere after use, there are no exhaust fume considerations. Also, if the work environment is wet, as it often is, there are no electric shock issues with which to be concerned, as would be the case with electrically powered equipment (unless driven hydraulically). Another benefit of using pneumatic grout machines is that unlike electric-powered machines, the speed of the various function motors is variable, and sometimes even reversible. Figure 5.6 shows one such pneumatically driven machine that incorporates a colloidal mixer, agitator, and progressing cavity pump on a single skid frame.

In summary, if there is access to plenty of compressed air, which is needed for operations other than grouting, then a pneumatically powered grout plant is a good choice; but if a compressor needs to be run solely to power the grout plant, a different power option may be a better choice.

Pneumatic Cylinders

Pneumatic cylinders can be the simplest of pneumatic components and offer a wide variety of applications on grout machines, from operating valves and gates to driving reciprocating pumps such as a plunger pump.

Courtesy of ChemGrout.

Figure 5.6 Pneumatically driven colloidal grout plant

Figure 5.7 illustrates a typical pneumatic cylinder, clearly showing the air inlet and exhaust ports at each end. When compressed air is introduced into one of the ports, an imbalance is created within the cylinder tube causing the piston to move. If air is introduced into the "extend" port, then the air pressure at the back of the piston is greater than that at the front, so the piston is forced to move forward, causing the rod to extend. The opposite action occurs when compressed air is introduced into the retract port, resulting in piston rod retraction.

If the cylinder is to be used for an intermittent activity, such as opening and closing a valve or gate, the direction of the air entering and leaving the cylinder is controlled by some kind of directional control valve, either operated manually or by some mechanical means such as a lever or cam that, in turn, is actuated by some related function.

Figure 5.8 is a schematic diagram of a typical two-position, four-way, lever-actuated valve that might be used to direct air flow into one or the other end of a pneumatic cylinder used for an intermittent function such as opening and closing a valve or gate. Port A is the compressed air source and port B is the exhaust port. When the handle is moved outward, the valve spool is moved to the left in the diagram, thereby directing the air flow to the rear of the cylinder, thus moving the piston forward, causing the rod to extend. At the same time, the air ahead of the piston is being exhausted through port B of the valve. To retract the rod, the valve handle is moved inward, causing the spool to shift and direct the air to the front of the piston, moving it to the rear of the cylinder. In each case, it is necessary to provide an exhaust path for air on the inactive side of the piston to prevent it from being trapped, thus interfering with movement of the rod.

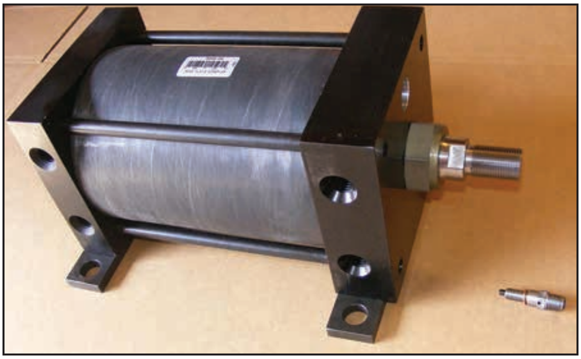


Figure 5.7 Pneumatic cylinder

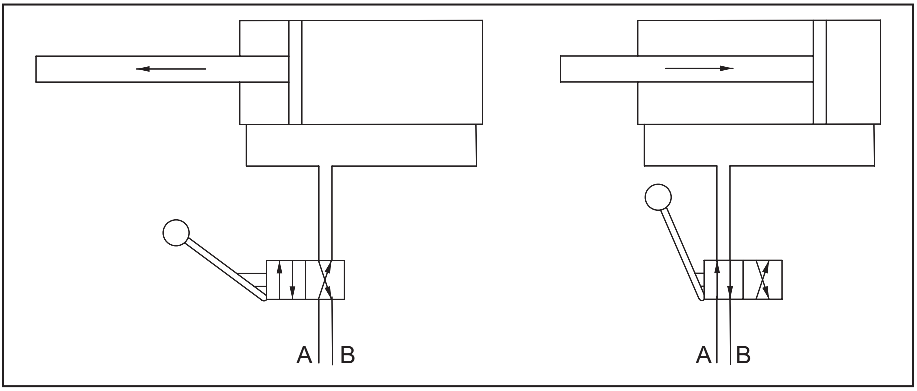


Figure 5.8 Simple extend/retract valve schematic

Maintenance and Repair

Over time, the function driven by the cylinder (pump, valve, etc.) may not be working as it should; that is, the pump is not cycling as fast or producing the correct pressure, or the valve is not closing completely and there is a sound of escaping air. These are all signs that the cylinder is ready for maintenance, possibly a complete overhaul that involves replacement of the piston, rod seals, and tube end gaskets or O-rings. In some cases, it may also be necessary to hone the tube bore. Figure 5.9 shows a cross section of a pneumatic cylinder.

Most manufacturers sell rebuild kits consisting of shaft seals, O-rings, gaskets, piston seals, and other parts required to keep the cylinder functioning efficiently for many years. Replacing seals on most pneumatic cylinders is a pretty simple, straightforward process (Figure 5.10). Table 5.1 provides torque values for tightening the tie rods in a pneumatic cylinder.

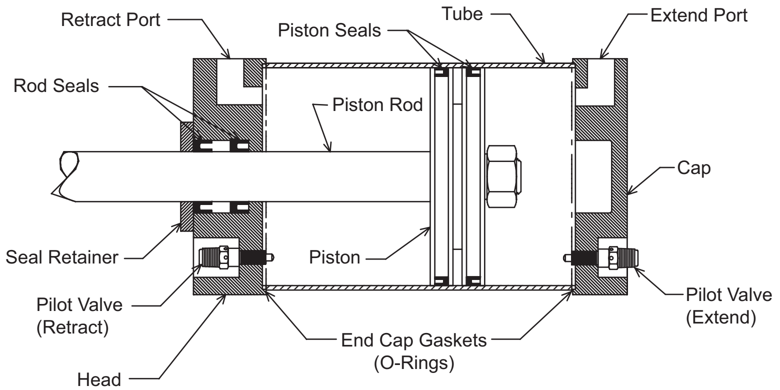


Figure 5.9 Pneumatic cylinder cross section

1. Remove cylinder from machine on which it is mounted. Start disassembly with rod fully extended.
2. Loosen tie rod nuts or bolts. This may require significant force, as these have been torqued during assembly at the factory.
3. Remove the head end cap (the end from which the rod extends). It may be possible to remove the piston at the same time.
4. Remove the "dead" end cap.
5. Remove the cap screws that attach the rod seal retainer, and remove the rod seals from their housing.
6. Remove the existing piston seals by prying them out of their retaining grooves. If these are U-cup seals, note the direction of the open side of the cup to ensure that the replacement seals are installed accordingly.
7. Carefully inspect the inside surface of the tube bore for nicks or scratches. If any are found, remove or minimize them by honing the bore with a cylinder hone.
8. Install new piston and rod seals, and remove and replace both end cap gaskets or O-rings.
9. Reassemble the cylinder in reverse order of disassembly. When replacing tie rods, lubricate the threads with a light oil, then tighten each rod or nut only hand tight at first to ensure that the tube is properly seated into each end cap. Next, with a wrench, gradually bring each nut or bolt to a moderately tight condition, working diagonally across the end cap.
10. Final tightening should be done using a torque wrench, tightening the rods to the values specified by the manufacturer or as listed in Table 5.1. The values shown in Table 5.1 are appropriate for Grade 8 tie rods.

Figure 5.10 Procedure for replacing seals on a pneumatic cylinder

Air Motors

The vane-type air motors used on many pneumatically powered grout machines consume enormous quantities of compressed air. Vane-type air motors do not generate enough torque at low revolutions per minute to accomplish any meaningful work, so they must be run at fairly high speeds where the torque values are high. For this reason, it is necessary to couple them with some type of speed reducer, such as the ones described in Chapter 6 on gearboxes.

Table 5.1 Threaded fastener torque chart

Diameter/TPI	Lubed in.-lb
¼–28	60–80
5⁄16–24	120–172
⅜–24	175–271
7⁄16–20	475–628
½–20	585–840
9⁄16–18	900–1,220
⅝–18	1,200–1,730
¾–16	2,400–3,500
⅞–14	2,750–4,650
1–14	4,600–7,250
1⅛–12	6,000–10,250
1¼–12	10,000–16,750

Source: USDOT FAA 2008.
*TPI = threads per inch.

Essentially, the air motor consists of a rotor with many axially oriented vanes mounted to a shaft. This assembly is encased by a heavy steel enclosure with a bore somewhat larger than the rotor assembly, the axis of which is slightly offset from the axis of the rotor assembly. The case has two radially oriented ports that are used for the introduction of compressed air: one is the induction port and the second is the exhaust port. Air passing through this chamber acts on the vanes, causing rotation of the rotor assembly.

Figure 5.11 illustrates how an air motor works. The rotor (part that rotates) is mounted in a larger cavity within the motor body in such a manner as to be offset from the center of the bore. The vanes are mounted within slots in the rotor so they can move freely and, aided by springs and push pins, are enabled to maintain contact with the cavity bore at every point of revolution. Compressed air entering the body case from either port acts on the vanes, causing the rotor to turn.

Air motor operating parameters function best at high rotational speeds where they obtain their highest torque and horsepower ratings; therefore, it is necessary to employ some type of speed reduction device for most applications. Since vane-type air motors have very little starting torque, as shown in Table 5.2, the speed reducer also acts to increase the apparent starting torque and helps get the motor started when under load. Table 5.2 shows vane-type air motor performance characteristics for the sizes of air motors most commonly found on grouting equipment.

Figure 5.12 shows a paddle mixer powered by a 6AM vane-type air motor driving the mixer paddle through a right-angle-type gearbox. Note the tee fitting on the lower air line, which is provided to introduce supplemental lubrication should the vanes become stuck and the rotor immobilized due to corrosion.

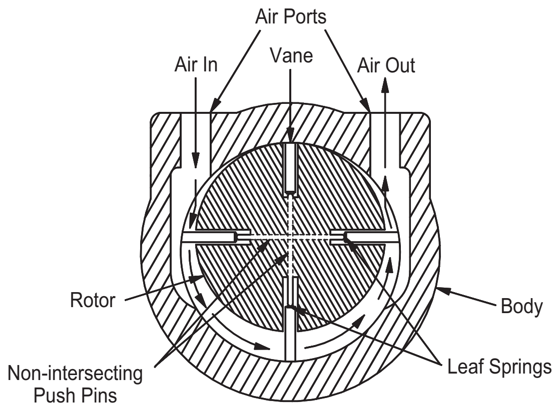


Figure 5.11 Vane-type air motor

Table 5.2 Vane-type air motor performance chart

Model	Maximum Speed, rpm	Output Power, hp	Torque, in.-lb	Maximum Air Consumption, cfm
4AM	3,000	1.7	36	78
6AM	3,000	4.0	84	128
8AM	2,500	5.25	132	175
16AM	2,000	9.5	290	275

Source: Gast Manufacturing 2012.

Maintenance and Repair

Although air motors have proven to be quite rugged and have been known to tolerate severe abuse and general disrespect and still keep running, a prudent operator will take necessary steps to enhance their longevity by keeping them well lubricated. This is usually accomplished by means of an air line lubricator. If the machine on which the motor is mounted is not to be used for some time or will be stored out of doors, it is a good idea to introduce some light

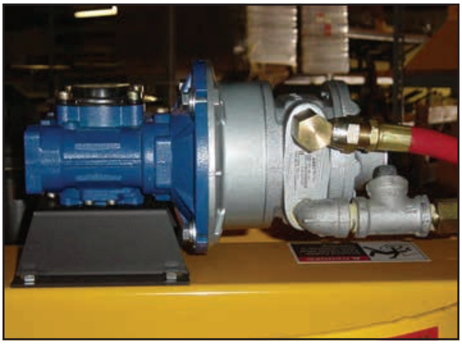


Figure 5.12 6AM air motor mounted on right-angle gearbox

oil directly into the motor by means of the tee on the air inlet line (see Figure 5.12) to protect it against corrosion. (Light-viscosity spray lubricants like WD-40 work well for this purpose.)

In addition to air line lubricators, all air motors should be protected against sand or grit particles entering the motor case via the air source. This can best be accomplished by means of a filter immediately behind the primary air hose connection and before the lubricator, thus trapping any foreign particles before they can enter the motors.

Minor and Major Overhauls

No matter how carefully an operator cares for the motor, eventually the vanes will wear and the motor will lose efficiency and power. Motor manufacturers recognize this and provide repair kits containing all of the parts needed to overhaul the motor. These kits are available from air motor manufacturers for all motor models.

Before tearing into the a motor that does not seem to be working as well as it should, the troubleshooting guide found in Table 5.3 should be consulted to ensure that some other external factor is not contributing to the apparent problem. The problem often results from simple fixes like kinked or plugged air hoses, or somebody's truck parked on an air supply line. In other words, look for any and all possibilities before making the commitment to overhaul a motor.

Despite grout machine manufacturers' sincere efforts to provide adequate compressed air conditioning in terms of filtration and lubrication, the exhaust ports of these motors are generally left open to the atmosphere, albeit through a muffler or other noise reduction device. Because these machines are usually used out of doors, the interiors of the motors are vulnerable to extreme variations of temperature and humidity that can, and usually do, result in corrosion of the main body surfaces on which the vanes make contact.

The continuously high rate of rotation plus the almost certain potential for internal corrosion and contamination takes a toll on the longevity of the vanes, resulting in reduced efficiency and eventual failure when the motor will no longer function. But this is a fairly slow process, and a prudent operator will be alert to changes in the equipment and thus be prepared to replace vanes as necessary. In addition, vanes have been known to suddenly break, seemingly for no reason, so it is a good idea to keep an overhaul kit readily available for each size motor used on the equipment.

For the air motor shown in the rebuild examples that follow, Gast Manufacturing of Benton Harbor, Michigan, produces a service kit containing all the parts needed for either a minor rebuild consisting of replacing worn or broken vanes or a major rebuild consisting of replacing vanes, bearings, seals, and gaskets. Other manufacturers may provide similar kits for their products, and the repair procedures would also be similar to those illustrated herein.

The rebuild service kit contains the following items required for either a major or minor rebuild (Figure 5.13):

- 1 Drive-end bearing
- 1 Dead-end bearing

Table 5.3 Air motor troubleshooting guide

Low Torque	Low Speed	Will Not Run	Runs Well, Slows	Reason and Remedy
✓	✓	✓		Dirt or foreign matter in air. Inspect and clean out.
✓	✓	✓		Internal rust. Inspect and flush out.
✓	✓			Low air pressure. Increase pressure.
	✓			Air line too small. Increase size.
	✓		✓	Restricted exhaust. Inspect and repair.
	✓	✓	✓	Motor jammed. Needs service; repair or overhaul.
	✓		✓	Air source inadequate. Inspect and repair.
	✓		✓	Air source too far from motor. Reconfigure setup.

Source: Gast Manufacturing 2003.

- 4 Vanes
- 4 Vane springs
- 2 Push pins
- 1 Shaft seal
- 2 Body gaskets
- 1 O-ring
- 1 End cap gasket
- 1 Muffler felt

Grouting operations are sometimes performed in remote locations where particular tools are not readily available. Therefore, fabricating often becomes necessary for an operator on a remote site to perform repairs and thus maintain production. Figure 5.14 shows a tool that can be fabricated to facilitate dead-end plate removal during the rebuild process. It was made from ¼-inch hot rolled steel plate and cut to a roughly hexagonal shape. The center hole has a ⅝-inch diameter to accommodate the gear puller bolt, and the three attach bolt holes correspond to the end cap bolt holes.

Figures 5.15 and 5.16 exhibit the procedures for a minor and major rebuild, respectively, of an air motor. The procedures are the same for 6AM, 8AM, and 16AM motors.

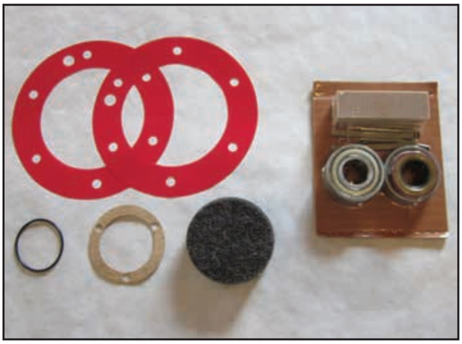


Figure 5.13 Service kit parts for minor rebuild

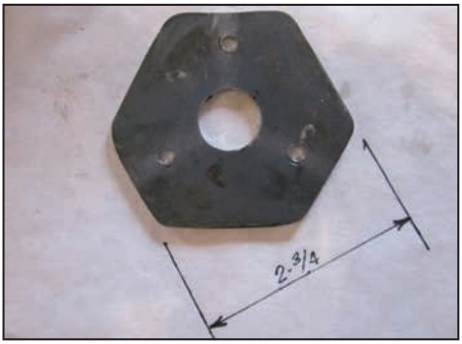
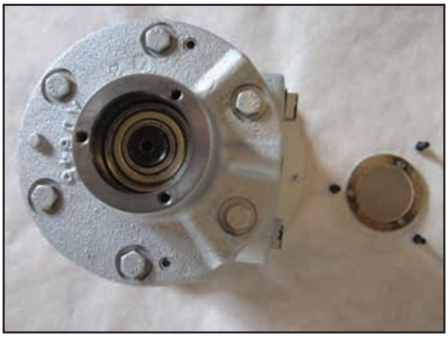
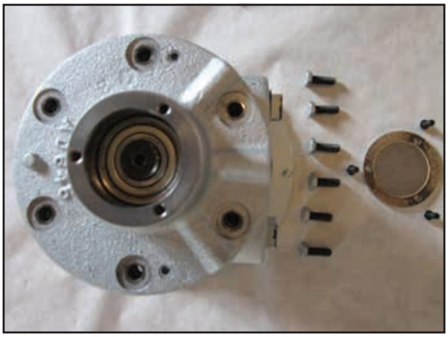


Figure 5.14 Fabricated tool for dead-end plate removal

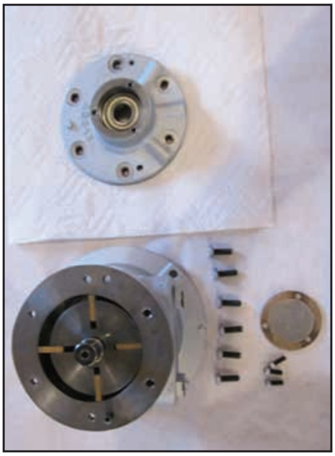


A. Remove dead-end cap.



B. Remove dead-end plate bolts.

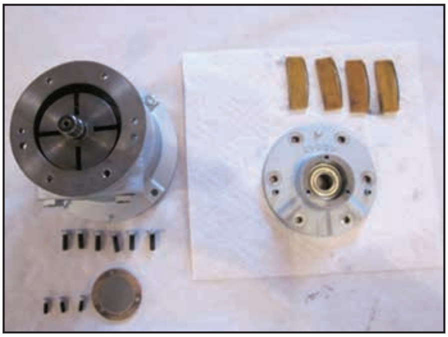
C. Remove dead-end plate.



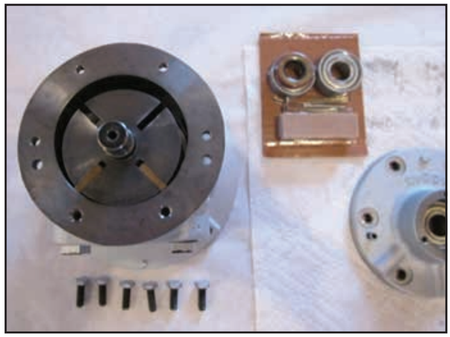
D. Remove dowel pins.

1. Remove the dead-end cap (Figure A).
2. Remove dead-end plate bolts (Figure B).
3. Remove dead-end plate (Figure C). The mating surfaces of the body and end plate are finely machined to prevent any air from escaping; therefore, do not attempt to pry the two apart. For this purpose, a special end cap was fabricated to allow the use of a small gear puller to remove the dead-end plate.
4. Remove the dowel pins from the body and push back into the end plate until flush with or just below the machined surface of the end plate (Figure D). The dead-end bearing is also removed with the end plate.

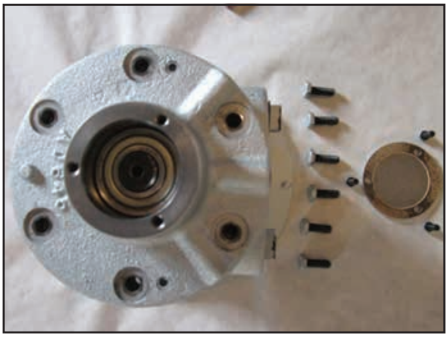
Figure 5.15 Procedure for a minor rebuild of an air motor (figure continues)



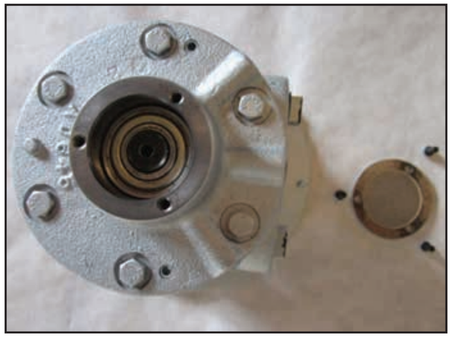
E. Remove vanes.



F. Oil and replace vanes.



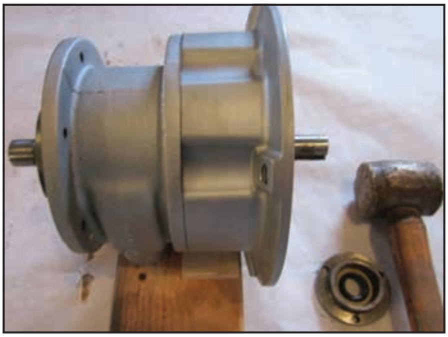
G. Place dead-end plate on body.



H. Reattach end cap.

5. Remove the vanes (Figure E).
6. Lightly oil and replace the vanes with new vanes from the service kit. The replacement vanes are provided in the service kit and shown to the right of the motor in Figure F.
7. Place the proper end plate gasket on the end plate. If the original has been damaged, replace it with a new one supplied with the service kit.
8. Place the dead-end plate on the body (Figure G).
9. Remove the bearing from the service kit and carefully press it onto the shaft, starting it with a ⅞-inch wooden dowel driven by a soft-blow hammer and finishing with a ¾-inch Schedule 40 pipe nipple with a cap and driven by a 2-lb hammer.
10. Tap the dowel pins into the body and install the end plate bolts. Tighten the end plate bolts to 75–100 in.-lb. Lightly strike the drive-end shaft with a soft hammer to push the rotor away from the drive-end plate. The rotor must not rub on either end plate.
11. Reattach the end cap (Figure H).
12. Put a few drops of light lubricant into one of the ports and turn the motor by hand to finish the rebuild procedure. The rotor must not rub on either end plate. The minor rebuild has now been completed.

Figure 5.15 Procedure for a minor rebuild of an air motor (continued)



A. Remove drive components and rotor.

B. Remove shaft seal and bearing.

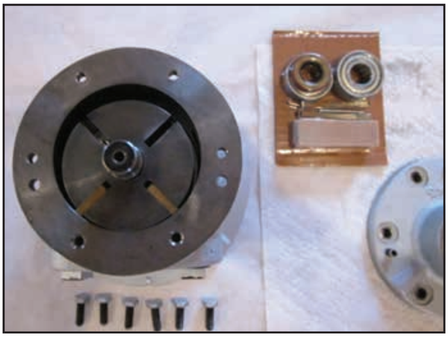
C. Install new push pins.

D. Install drive-end bearing.

Perform steps 1–5 from the minor rebuild procedure in Figure 5.15, then proceed with the steps below:

1. Remove drive components such as pulleys, and so on, and clean the drive shaft with a file or emery cloth. Remove the rotor using an arbor press (Figure A). (Note: If an arbor press is not available, a heavy brass or lead hammer [like the one shown in the figure] can be used to drive out the rotor.)
2. Remove the shaft seal from the drive-end plate (Figure B). Do not remove the drive-end plate bolts or drive-end plate. Absent an arbor press, a ¾-inch pipe nipple is the right size for this application; light taps with a hammer are all that is required to drive the seal from the drive-end cap.
3. Clean all parts and inspect for scoring of the end plates. If scoring exists, the motor cannot be rebuilt except by personnel at an authorized service facility.
4. Remove the bearing from the drive-end plate and install new push pins from the service kit in the rotor (Figure C). A ¾-inch wooden dowel and light hammer are sufficient to remove the bearing from the drive-end plate. (Note the new push pins adjacent to the rotor.)
5. Insert the drive shaft of the rotor assembly through the drive-end plate and press the drive bearing onto the drive shaft. The ¾-inch pipe nipple previously used to remove the shaft seal should perfectly contact the inner race of the drive-end bearing; a few taps from a heavy hammer should install the drive-end bearing (Figure D).

Figure 5.16 Procedure for a major rebuild of an air motor (figure continues)



E. **Install new vanes.**

F. **Replace gasket.**

G. **Install dead-end bearing.**

H. **Install dowel pins and tighten bolts.**

6. Install new vanes from the service kit (Figure E).
7. Place the proper end-plate gasket on the body at the dead end and place the dead-end plate on the body (Figure F). If the original gasket has been damaged, replace that gasket with one from the service kit. Insert the bolts and tighten them until just snug.
8. Install the dead-end bearing and press into place in an arbor press (Figure G). (A ¾-inch pipe and hammer can be employed for this purpose.)
9. Install the dowel pins and fully tighten all bolts to a torque value of 75–100 in.-lb (Figure H). Install the drive-end bearing seal in the drive-end cap and install the drive-end cap onto the drive-end plate with three screws. Place a new cap gasket on the dead-end plate and attach the dead-end cap to the dead-end plate with three screws.
10. Check for proper operation by turning the drive shaft by hand; the shaft should rotate smoothly without scraping either of the end plates. The major rebuild has now been completed.

Figure 5.16 Procedure for a major rebuild of an air motor (continued)

Courtesy of ChemGrout.

Figure 5.17 16AM series air motor driving size 6 progressing cavity pump through sheaves and belts

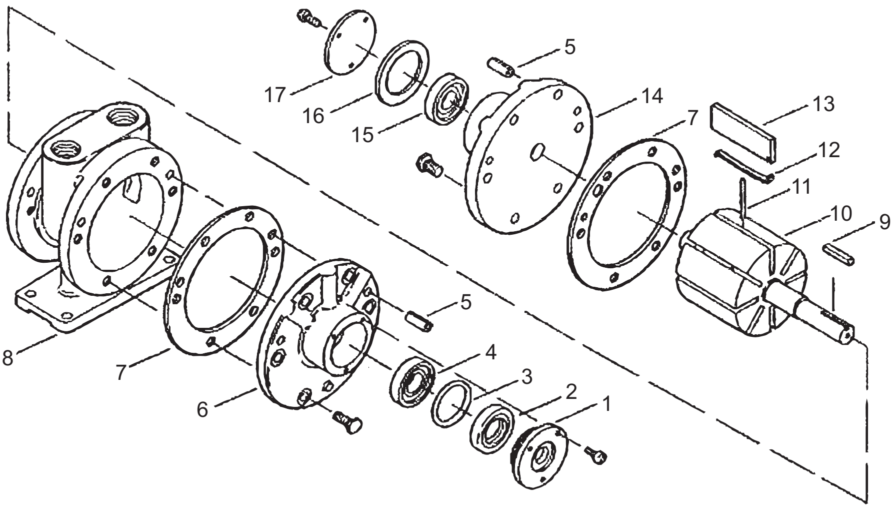
The repair suggestions offered herein assume that repairs will be conducted in the field with tools and accessories normally available to grout operators working in those circumstances and without the advantages and amenities of a fully equipped repair shop.

6AM, 8AM, and 16AM Series Rebuild

The 6AM and 8AM motors are generally used for mixer and agitator drives or for pump drives on some smaller rotary pumps, such as size 3 and size 4 progressing cavity pumps. The larger 9.5-hp 16AM motors are usually employed to drive size 6 or larger progressing cavity pumps through an arrangement of sheaves and belts that serve to reduce the speed of the motor as well as to multiply applied torque, as illustrated in Figure 5.17.

The instructions for rebuild of the 6AM and 8AM motors apply to 16AM motors as well, the only exception being that the drive-end bearing is retained in the 16AM motor by a nut and lock washer that must be removed to replace the drive-end bearing.

After many years of use and possibly storage of the equipment outdoors, as is often the situation, the main housing or body of the motor may become corroded or grooved from the introduction of grit and other foreign materials during operation. If this is the case, the efficiency of the motor will have severely degraded, if the motor will run at all. Should this occur, it is possible to hone or machine the bore to provide a smooth surface for the vanes to contact, thus restoring the efficiency of the air motor.



1	Drive-End Cap	10	Rotor Assembly
2	Shaft Seal	11	Push Pin *(2 or 4 required)*
3	O-Ring	12	Vane Spring *(4 or 8 required)*
4	Drive-End Bearing	13	Vane *(4 or 8 required)*
5	Dowel Pin *(4 required)*	14	Dead-End Plate
6	Drive-End Plate	15	Dead-End Bearing
7	Body Gasket *(2 required)*	16	End Cap Gasket
8	Body	17	Dead-End Cap
9	Key		

Courtesy of Gast Manufacturing.

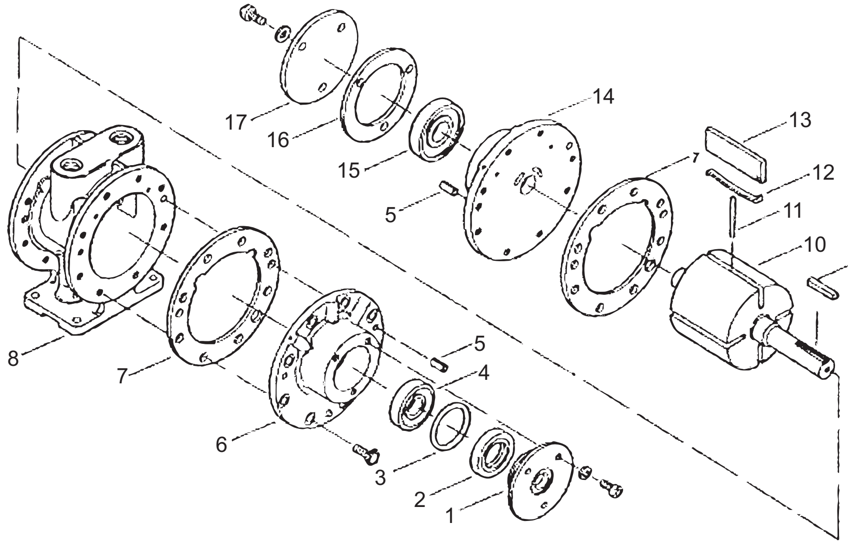
Figure 5.18 6AM series parts drawing

Although there are several air motor manufacturers worldwide, literature from only one domestic manufacturer has been included here because these are the motors most frequently supplied on domestically manufactured grouting equipment. With only minor differences in terms of mounting styles and dimensions (SAE [Society of Automotive Engineers] vs. metric), all of the vane-type air motors manufactured today are similar in design and construction, and they function somewhat equally.

The parts lists and diagrams reproduced in Figures 5.18, 5.19, and 5.20 are courtesy of Gast Manufacturing and are relative only to products manufactured by them. This type of motor is used extensively on pneumatically powered grouting equipment.

Radial Piston Air Motors

The radial piston air motor was at one time built in large quantities to service mining applications such as hoisting and tramming operations, particularly in coal and metal mines. The primary advantage of piston air motors over vane-type air motors is their high-torque capabilities that allow them to start under load. In addition, they cover a



1	Drive-End Cap	10	Rotor Assembly
2	Shaft Seal	11	Push Pin *(2 or 4 required)*
3	O-Ring	12	Vane Spring *(4 or 8 required)*
4	Drive-End Bearing	13	Vane *(4 or 8 required)*
5	Dowel Pin *(4 required)*	14	Dead-End Plate
6	Drive-End Plate *(2 required)*	15	Dead-End Bearing
7	Body Gasket *(2 required)*	16	End Cap Gasket
8	Body	17	Dead-End Cap
9	Key		

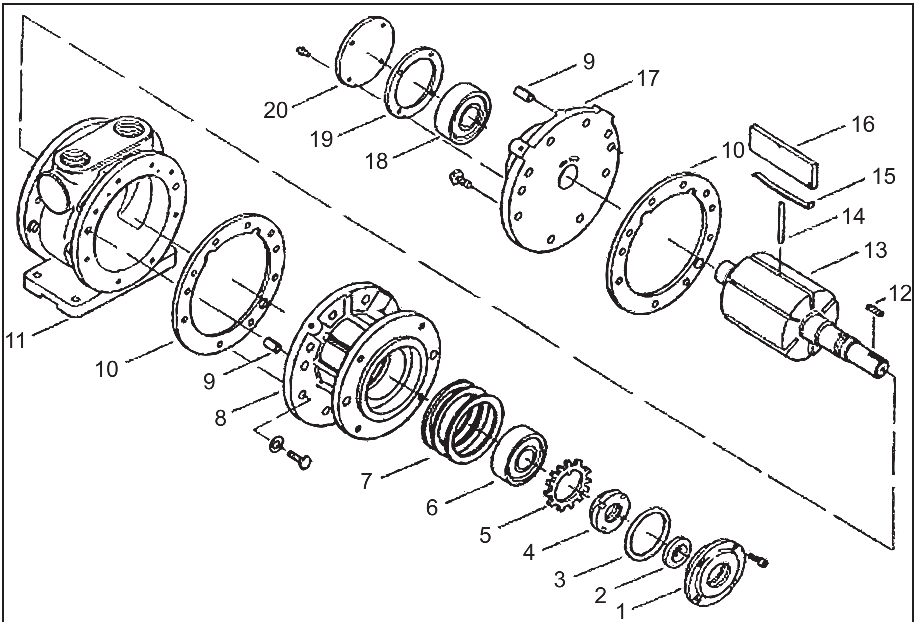
Courtesy of Gast Manufacturing.

Figure 5.19 8AM series parts drawing

horsepower range far beyond the typical vane-type air motor. However, in recent years, hydraulically driven machinery has been developed to perform many of these operations; as a result, radial piston air motors are rarely used anymore.

Manufacture of piston air motors has slowed precipitously because manufacturers are reluctant to stock a product with a very thin market; as a result, there are now exceedingly long lead times from order to delivery. For this reason, these motors are now difficult to locate and obtain.

There are so few piston air motors in use anymore that the mechanics of these air motors will not be covered in this manual beyond what has already been discussed. Repair or overhaul instructions will also not be offered, as the complexity of these motors requires refurbishment by trained professionals.



1	Drive-End Cap	11	Body
2	Seal	12	Drive Key
3	O-Ring	13	Rotor Assembly
4	Lock Nut	14	Push Pin *(3 required)*
5	Lock Washer	15	Vane Spring *(6 required)*
6	Drive-End Bearing	16	Vane *(6 required)*
7	Spacer	17	Dead-End Plate
8	Drive-End Plate	18	Dead-End Bearing
9	Dowel Pin *(4 required)*	19	End Cap Gasket
10	Spacer Gasket *(2 required)*	20	Dead-End Cap

Source: Adapted from Gast Manufacturing 2003.

Figure 5.20 16AM series parts drawing

Air Line Lubricators

To keep pneumatic cylinders and air motors functioning correctly and to enhance the longevity of these components, they must be kept properly and adequately lubricated, which is done by means of air line lubricators, often called “oilers.”

An air line lubricator attaches directly to the air supply line of pneumatically powered equipment. Its purpose is to supply lubrication to any motors or cylinders downstream of the air supply. The reservoir is filled with special air tool oil available at any contractor’s supply house. As the air passes through the oiler, a very small amount of oil is drawn from the reservoir into the air stream, becoming a fine mist, which keeps the motors or cylinders lubricated.

Figure 5.21 Air line lubricators

An adjusting screw inside the unit allows adjustment of the oil stream, and this should be adjusted so that only a very small amount of oil is used. If there is evidence of oil dripping from the mufflers, then too much oil is being used. Conversely, if the oiler does not have to be filled every day, not enough oil or none is being used.

In Figure 5.21, the upper unit near the middle of the photo is a combination filter/regulator/lubricator that is conditioning the air being supplied to an air cylinder driving a reciprocating pump. The lower device is a typical air line lubricator with the filler cap clearly visible on the top. The adjusting screw is located immediately under the cap.

A typical air line lubricator suitable for all low-volume (less than 330 cfm air flow) compressed air operated devices, including cylinders and motors, is illustrated in Figure 5.22. Air line oilers also exist for air flows beyond 330 cfm, but they are of much more robust construction and feature a larger-capacity oil reservoir.

The air line lubricator is installed into the compressed air line ahead of the component to be lubricated, usually an air cylinder or motor. As the air is consumed by the component activity, it passes through the lubricator where its velocity is increased by means of a built-in venturi, thus creating a partial vacuum that draws a small amount of lubricant (usually a lightweight oil) into the air stream where it is atomized and carried to

1. Adjusting screw: Reduces the amount of oil delivered by turning the screw in and increases the amount of oil delivered to the air stream by turning it out.
2. Body: The part to which the air line connects and may have port sizes from ⅛-inch NPT (National Pipe Thread) to 1¼-inch NPT.
3. Sight glass: Allows the operator to see how much lubricant is in the reservoir bowl.
4. Reservoir bowl: The container that holds the oil supply and place from which the oil is dispensed.
5. Filler cap.

Courtesy of ChemGrout.

Figure 5.22 Small-capacity air line lubricator

the operating component, thus maintaining lubrication. The adjusting screw is used to proportion the correct amount of oil to the volume of air being consumed to avoid excessive lubrication resulting in oil spillage from the exhaust port of the device being lubricated while still maintaining sufficient lubrication.

These types of lubricators are often supplied in conjunction with other air-conditioning components, such as filters to remove particulate matter from the air supply and pressure regulators to adjust the incoming air pressure to various operating components. Although filters are very often placed in the air line ahead of the lubricator, there is seldom a need to regulate the air pressure because in grouting and related operations it is most desirable to receive the highest possible air pressure to satisfy any application need.

Figure 5.23 High-capacity air line lubricator

Shown in Figure 5.23 is a high-capacity air line oiler of more robust construction that is better suited to high-volume air consumption as would normally occur with large air motors or a circuit containing multiple air motors.

CAUTION: These units are under pressure from the air line whenever the machine is in service. DO NOT REMOVE THE CAP OR OPEN THE UNIT until the air line has been removed from the compressed air source and kinetic energy is relieved from the machine.

REFERENCES

Gast Manufacturing, Inc. 2003. *AM Series Lubricated Air Motors: Operation and Maintenance Manual.* Benton Harbor, MI: Gast Manufacturing.

Gast Manufacturing, Inc. 2012. *Air Motor Catalog D-10.* Benton Harbor, MI: Gast Manufacturing.

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6

Power Transmission

GEARBOXES

Because of the high speeds of drive motors for mixers and agitators (discussed in Chapter 3), whether air or electric, it is necessary to reduce those speeds to rates that are compatible with the activity being performed. In the case of paddle mixers, the paddle speed should be between 90 and 100 rpm; with agitators, the speed of the paddle should be between 40 and 60 rpm.

Traditionally, this speed reduction has been performed by some kind of gearbox, and the most frequently chosen gearbox was a single-reduction right-angle worm gear speed reducer (Figure 6.1), which is a fairly simple device. It consists of an input shaft to which a drive motor is attached and has a worm gear that meshes with a ring gear to which the output shaft is attached. These gearboxes are available in a variety of ratios to obtain the desired final speed. For example, if a mixer is to be powered electrically and the electric motor speed is 1,750 rpm and the mixer paddle speed is expected to be 90–100 rpm, then a single-reduction worm gear reducer with a reduction ratio of 17.5 to 1 would result in the ideal desired paddle speed of about 100 rpm.

Unfortunately, most, if not all, gearbox manufacturers start their ratios at 4:1 or 5:1, and then proceed to 7½:1, then 10:1, 15:1, 20:1, and so forth, in increments of fives. So to satisfy the previously described hypothetical mixer requirement, the choice would have to be either 15:1 or 20:1. A ratio of 20:1 would yield a paddle speed of 87.5 rpm, which is a little too slow to obtain adequate mixing for most grout materials, whether sanded or slurry mixes. This leaves 15:1 as the remaining choice, which will yield a paddle speed of 116.7 rpm. This is just a bit faster than ideal, but it will produce a well-mixed material and is a better choice among the limited choices. This is the most commonly used speed reducer encountered on grout machine mixers.

Agitators are required to run much slower than mixers because their function is simply to keep the materials that have already been mixed in suspension and ready for pumping. Normal agitator speed is between 40 and 60 rpm. Solving for 50 rpm with the same

Figure 6.1 Typical right-angle worm gear speed reducer

Figure 6.2 Worm gear speed reducer powered by an electric motor

1,750-rpm electric motor would require a gearbox with a 35:1 ratio, and if one preferred to raise the agitator paddle revolutions per minute to the upper level of 60 rpm, this can easily be accomplished with a 30:1 gearbox ratio. Figure 6.2 shows a 30:1 ratio gearbox attached to an agitator and powered by an electric motor. (In comparison, Figure 5.12 in Chapter 5 shows a 15:1 ratio gearbox attached to a paddle mixer and powered by an air motor.)

Maintenance

Worm gear speed reducers are extremely robust, so much so that very little attention is typically paid to them and most grout operators are unaware of the maintenance procedures required to ensure a long and trouble-free life for these components. Maintenance procedures for these units consist of nothing more complicated than proper lubrication and periodic condition monitoring until it becomes time for repair or rebuild. In actual use, manufacturer recommendations are generally ignored and the original lubricant supplied with the gearbox remains until either the end of the unit's productive life or it has leaked out through worn or broken seals.

Lubrication

At some convenient standard interval (e.g., every 3 months), all of the oil should be drained from the gearbox and replaced with the manufacturer's suggested lubricant for the unit's level of service.

Each gearbox is filled at the factory with the appropriate grade of lubricant for operation in ambient temperatures of between 51°F and 110°F and is adjusted for proper level. Except for very extreme conditions (e.g., operation during extended periods of cold temperatures), this lubricant is adequate for most general applications in temperate or tropical climate zones (ChemGrout 2012).

Table 6.1 Suggested lubricants for gearboxes*

Supplier	Product Name
Cities Service Corporation	SPO-288
Gulf Oil Company	Transgear EP 680
Mobil Oil Corporation	Mobil 600 W Super
Shell Oil Corporation	Omala 680
Texaco, Inc.	Honor Cylinder Oil 680
Chevron Oil Company	NL Gear Compound 680

Source: ChemGrout 2012.
*This list does not include all manufacturers or products; local distributors may have appropriate products that do not appear on this list. In general, any gear oil with an ISO (International Organization for Standardization) grade of between 460 and 680 is appropriate for use in this type of gearbox.

The following instructions are offered for maintaining the gearbox in optimum condition so as to extend the duration of its service life:

- *Initial oil change.* The oil in a new gearbox should be changed at the end of 250 hours of operation (30 days for 8-hours-per-day service, 15 days for 16-hours-per-day service, 10 days for 24-hours-per-day service). Table 6.1 lists suggested lubricants.
- *Subsequent oil changes.* Under normal conditions, after the initial oil change, the oil should be changed after every 2,500 hours of operation, or every 6 months, whichever comes first. Under severe conditions, it may be necessary to change the oil more frequently at intervals of 1 to 3 months. Periodic examination of oil samples taken from the unit will help establish the appropriate interval.

  The drained oil should be carefully examined for metal fragments or chips, as this is an indication of excessive wear to either the ring gear or the worm gear. Generally, it is the ring gear that will wear first because most manufacturers use a softer metal for the ring gear than for the worm gear. This is to prevent breaking the case should the unit become overloaded. In any event, if metal chips are found in the drained oil, the worn ring gear will need to be replaced as quickly as possible; once wear has started, it will quickly advance to the point where the gearbox becomes unusable.
- *Overfilling or underfilling.* The gearbox is equipped with ⅛-inch NPT plugs at appropriate places to serve as fill level indicators in all possible mounting positions. When refilling the gearbox after an oil change, the plug in the side of the box needs to be removed to ensure that the oil level does not exceed this limit. (Remember to replace plug after filling.)

Venting

During operation, heat generated within the gearbox will cause the air and lubricant inside the unit to expand. A vent (in the topmost plug) has been provided to relieve the

resulting pressure. This vent must be kept clean and in working order to prevent buildup of excessive pressure that could damage the seals (Figure 6.3).

Repair

This section describes various repairs that can be performed on the single-reduction right-angle worm gear–type speed reducers that have been described in this chapter. The repair procedures described herein assume that the repairs are being performed in the field with standard hand tools normally available on a grouting site rather than in a fully equipped repair shop.

Seals

The most common repair procedure involves the replacement of worn or damaged seals. It is necessary to frequently monitor the lubricant level in the gearbox to determine whether sufficient oil is available to keep the gears lubricated. If the oil level needs to be "topped up" from time to time, this may be an indication that the seals are leaking. In addition to exposing the gearbox to low oil levels, the oil may be leaking into the mixer and contaminating the grout. Figure 6.4 shows the procedure for replacing leaking seals.

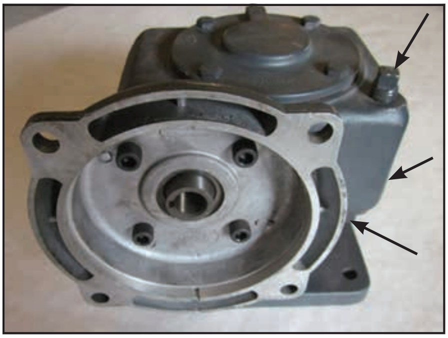
Worm Gear

Probably the second most frequently performed repair procedure is replacement of the worm gear. The worm gear is fabricated of bronze or some other less noble metal than the worm shaft and is thus purposely more vulnerable to wear or damage than is the shaft. Although this is not necessarily a weakness, the worm gear can be damaged by lack of proper lubrication or from chronic excessive overload, but if it is damaged, it can be replaced as shown in Figure 6.5.

Because the worm gear replacement procedure illustrated in Figure 6.5 is also being used to illustrate bearing replacement, a second bearing pusher can be fabricated to install the dead-end bearing (Figure 6.6). The second bearing pusher should be made to a size of 2 inches in diameter with a 1-inch-diameter hole. Because the bearing has to be pulled in from the live end of the shaft, this necessitates replacing the original gear puller jaws with longer jaws. Had this bearing not been removed for the bearing replacement procedure, the longer jaws shown in Figures 6.7 and 6.8 would not be needed.

With the new worm gear on the output shaft, the shaft may be returned to the case, the gear meshed with the worm shaft, and the case reassembled. When assembling the motor adapter plate and the gearbox base assembly, a light film of silicone caulk needs to be applied on the mating face as well as a small dab of caulk on each bolt before threading them in. This will ensure against leaks when the case is filled with oil.

Figure 6.3 Vented plug



A. Locations of ⅛-inch NPT plugs

B. Gearbox base bracket and motor mounting flange

C. Seals removed from gearbox base bracket

1. After separating the drive motor from the gearbox, remove the gearbox from the grout machine and drain the oil by removing all of the ⅛-inch pipe plugs from locations shown in Figure A.
2. Remove the gearbox base bracket and the motor mounting flange (Figure B).
3. Drive out the old seals (Figure C). Various sized half-inch-drive socket wrenches with extensions have been found to be the ideal seal-removal tools. A lead hammer can be used to avoid damaging the socket with an extension used to drive out the seals. Coat the outside diameter of the new seals with a film of silicone caulking material before driving them back in place in the same manner.

Figure 6.4 Procedure for replacing seals

Bearings

The procedure for replacing bearings is shown in Ftigure 6.9. The input shaft bearings in this discussion are integral single-row ball bearings pressed onto the shaft. The bearings on the output shaft are two-piece tapered roller bearings with the inner race, including rollers and retainers, pressed onto the output shaft. The outer races are pressed into pockets in

A. Worm gear and output shaft removed from case

B. Three-jaw gear puller drawing worm gear and bearing off live end of shaft

C. Three-jaw gear puller drawing new worm gear toward dead end of shaft

First, perform steps 1, 2, and 3 in Figure 6.4 (as long as the gearbox is apart, the seals might as well be replaced), then proceed with the following steps:

1. Remove dead-end covers from both the output shaft and the input shaft; then extract the output shaft with the worm gear from the case (Figure A).
2. Using a three-jaw gear puller (Figure B), affix the jaws to the worm gear and pull against the shaft. The gear is keyed to the shaft but is not retained in any other way, so it can be removed from the shaft from either direction. If the bearings are not damaged and can be reused, it is suggested to pull the gear toward the long end of the shaft, because during reassembly, the bearing at that end is more easily assembled than the one at the short end.

   If the bearings are to be replaced at the same time, then drawing the worm gear toward the short end would be best because the gear will then push the bearing off the shaft. Without the worm gear to act as a bearing pusher, the short (dead) end bearing is more difficult to remove than the long (live) end bearing.
3. Mount a new worm gear on the shaft using the same three-jaw gear puller used to remove the gear (Figure C). Insert the square key into the shaft keyway and ensure that the keyway in the new gear is aligned with the key. It is also helpful to file or grind a slight angle on the leading edge of the key to help with alignment as the gear is drawn over the key.
4. Having successfully installed a new gear on the output shaft, it is now necessary to reinstall the bearing that came off the output shaft with the gear.

   Note: Another less commonly found tool is required to remount the bearing without causing damage by the gear puller. One can be fabricated by cutting a 3¼-inch circle from a piece of ⅛-inch hot rolled mild steel with a hole saw, then drilling a $\frac{25}{32}$-inch hole in the center (see Figure 6.6). This disc acts as a bearing pusher providing a place for the gear puller jaws to grasp and allowing the jaws to clear the newly installed worm gear.

Figure 6.5 Procedure for replacing worm gear

Figure 6.6 Fabricated bearing pushers

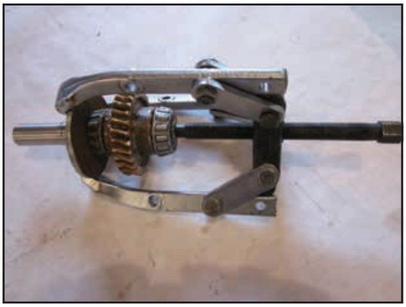


Figure 6.7 Seating live end bearing with bearing pusher

Figure 6.8 Long gear puller jaws with additional bolt hole

the gearbox mounting base bracket and the dead-end cover.

This is known as a cup-and-cone bearing, the cup being the outer race and the cone being the inner race, including the rollers and roller retainer. Whereas the inner races (cones) can be removed from the output shaft as previously discussed, the cups are difficult to remove without special tools and should not generally be attempted under field conditions unless they are severely pitted or corroded.

The procedures described in Figures 6.5 and 6.9 were performed on a Morse Model GCV18-RD-56C 15:1 gearbox, which is commonly used on air-powered and electrically powered grout mixers and agitators. Similar gearboxes by other manufacturers may differ in some construction details, and these will likely require revisions in the way the procedures are performed, but these general procedures and principles are applicable to all single-reduction worm gear–type gearboxes, regardless of manufacture.

SHEAVES AND BELTS

The most prevalent mechanical means of operating rotary equipment such as progressing cavity pumps and colloidal mixers is some kind of arrangement of sheaves and belts. For the purpose of this discussion, *sheave* is defined as any pulley of any size used to provide rotary motion to a device by means of V-belts.

Usually, the reason an equipment manufacturer will choose to employ this means of driving a function is to reduce the speed of the driving motor, whether pneumatic or electric, to the speed required by the device being driven. Sheaves and belts are generally more economical for this purpose than other speed-reducing devices, such as gearboxes,

A. Draw worm gear toward dead end of shaft.

B. Disassembled gearbox.

1. Disassemble the gearbox as described in steps 1 and 2 of Figure 6.5 (procedure for replacing worm gear), except instead of drawing the worm gear toward the *live* end of the shaft, proceed as shown in Figures A through C in this procedure.
2. To replace the bearings, draw the worm gear toward the *dead* (short) end of the shaft (Figure A) rather than the live (long) end. The reason for this is to use the worm gear as a bearing pusher to remove the dead-end bearing that is butted up to the worm gear and would otherwise be difficult to remove.
3. Having removed the dead-end bearing, use the larger bearing pusher to pull the live end bearing off of the long end of the shaft. This is to give the bearing puller jaws something on which to grip without causing damage to the bearing cone.
4. Remove the input (worm) shaft (shown in lower right of Figure B) from the gearbox case. Removal might require a few taps at the dead end with a light plastic or rubber mallet.

Figure 6.9 Procedure for replacing bearings (figure continues)

and offer a further advantage of unrestricted access to both the driver and the driven units in case of equipment breakdown or malfunction.

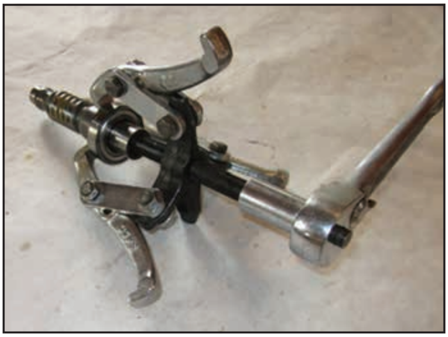
Sheave Selection

When selecting the size and type of sheaves that may be used for a specific application and what type of belts are best suited to that use, the manufacturer will employ five criteria:

1. Type of application (What kind of work? Grout pump, mixer, other?)
2. Horsepower rating and speed (rpm) of the drive motor
3. Desired speed (rpm) of the driven machine (pump, mixer, etc.)
4. Approximate available center distance between sheaves
5. Hours and intensity of operation (service factor)

The shaft sizes of the driving motor and the driven device are also important in the decision, as is the physical space available for the sheaves themselves. Sheaves are available

C. Remove input shaft bearings (dead end).



D. Remove input shaft bearings (live end).

5. Use the three-jaw gear puller to remover the bearings from each end (Figures C and D).
6. Install the new bearings on the input shaft by now reversing the position of the three-jaw puller to draw the bearings onto the shaft instead of off the shaft. To install new cone bearings to the output shaft, proceed in the same manner as reassembly of the output shaft after installation of a new worm gear, making use of the bearing pushers that were fabricated for that purpose.
7. Pack the bearings with a high-quality lithium-based grease and reinstall in the case along with the motor adapter plate and the dead-end cover plate. Coat the mating surfaces of the motor adapter and dead-end cover plate with a thin film of silicone caulk and add a dab of silicone caulking to each of the cap screws prior to threading them into the case. This will prevent leakage from the bolt holes when the case is filled with oil.
8. Pack the cone bearings on the output shaft with high-quality lithium-based grease, and having first attached the output shaft dead-end cap, insert the output shaft into the case, making sure that the worm gear has properly meshed with the worm of the input shaft. When you are certain that the output shaft is in correct position, install and attach the gearbox base bracket, having applied a thin film of silicone caulking to the mating surface of the bracket and a dab of silicone caulking to each of the cap screws as in step 7.
9. When satisfied that all parts have been correctly installed and are working freely, apply final torque to all of the attaching cap screws. Torque all ¼-inch–20 hex head and socket head cap screws to 75–85 in.-lb. Torque 5⁄16-inch–18 socket head cap screws to 155–175 in.-lb.
10. Replace the ⅛-inch NPT plug in the bottom of the case and stand the unit with the base bracket on a level surface. Using a small funnel, slowly fill the case with the proper grade of lubricating oil until it reaches the level of the ⅛-inch NPT plug located near the middle of the unit. This is the correct level for the oil, and this plug may now be replaced. Having retained the vented plug, this may now be installed in the topmost (fill) hole in the case, and all plugs securely tightened. The gearbox may now be returned to service.

Figure 6.9 Procedure for replacing bearings (continued)

either bored to size or configured for tapered bushings, so various shaft sizes can be easily accommodated. Once the speed ratio is known, there will be a variety of sheaves available to produce the appropriate speed, but there may only be sufficient room on the equipment for a specific combination of sheaves, and this is usually the minimum practical size.

When dealing with an existing piece of equipment for which belts or other drive components must be replaced, it is possible to identify each of the drive components in terms of type and size because all sheave manufacturers will stamp or otherwise mark each piece with a part number that can be cross-referenced with the manufacturer's catalog to reveal details of the component, such as bushing type, pitch diameter, and type of belt required. This is a good place to start when making repairs.

The repairs most frequently required for sheave-and-belt-driven equipment are replacement of worn or missing drive belts. If the belts are actually missing from the machine, it will be necessary to determine what size belts are required for replacement. A few ways to do this are discussed in the next section.

Determining Belt Length

The most frequent reason for needing to determine belt length is when it becomes necessary to resurrect a piece of equipment that had been in casual outdoor storage for a number of years and from which the belts are missing. The easiest way to do this is to adjust (by whatever means) the center distance between the driver and driven sheaves to the minimum, then wrap a length of ½-inch- or ⅝-inch-diameter rope around both sheaves and mark where they join. Measure this length, add two inches, and multiply by 10. This will be the size belts for replacements. For example, if the rope measurement is 43 inches, add 2 inches for a total of 45 inches, then multiply by 10, which equals 450—the belt to be purchased will be 5L450.

V-belt manufacturer's catalogs offer belt length formulas from which the length of the belt required for the hypothetical drive may be calculated. These methods are sometimes complicated and difficult to use; it seems that even using the formulas, belt length selection is more or less arbitrary and often results in making the best selection among two or three choices. However, if the sheave sizes are known, or can be measured, and the center distance is known, the same catalogs will often provide tables from which the belt size can be derived.

A more graphic method of calculating the belt length required is illustrated in Figure 6.10 in which a 15½-inch-diameter sheave is driven by a 3½-inch-diameter sheave with a center distance between them of 17 inches. Whatever means is employed to determine proper belt length, the replacement procedure is described in the next section.

Maintenance

With equipment that uses sheaves and V-belts to transmit power from a drive motor to one or more of the machine functions, it is of paramount importance that the condition of the drive components be constantly monitored. The drive belts must be kept clean and as tight as necessary to prevent slippage, and the sheaves must be maintained in

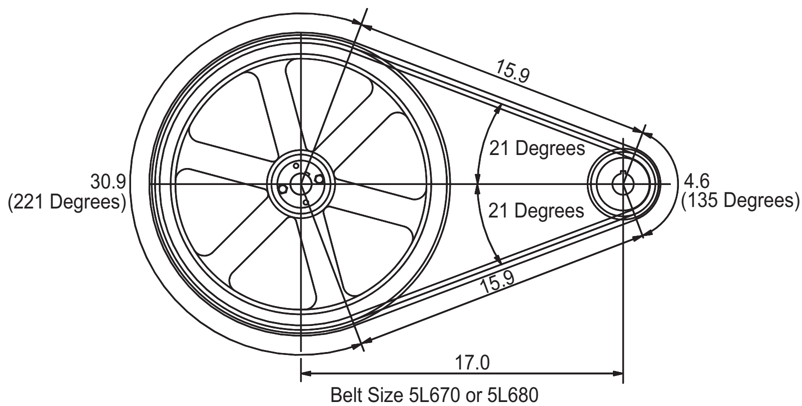


Figure 6.10 Belt length calculation

1. Secure the machine for safety as described in Chapter 1.
2. Remove the belt guard.
3. Loosen the idler or tightener, if so equipped, or adjust the drive motor to slacken the belts.
4. Remove worn belts.
5. Install new belts and readjust the drive motor or reinstall the idler, if so equipped.
6. Replace the belt guard.
7. Return the machine to service after testing for proper operation.

Figure 6.11 Procedure for changing belts

proper alignment to prevent belt damage. Slippage and misaligned sheaves will result in premature wear of the belts and, in extreme cases, will cause the belts to ravel and break. Therefore, the primary maintenance issue with sheave and belt drives is belt wear, which means that the most frequently performed maintenance procedure is changing worn belts. When engaged in that activity, the operator or mechanic needs to follow the safety suggestions offered at the beginning of this manual, even for such a simple operation. The steps for changing belts are listed in Figure 6.11.

HYDRAULICS

Until perhaps the late 1960s, mechanically driven grouting equipment prevailed, which used sometimes complex arrangements of clutches, sheaves, belts, and gearboxes of various kinds, as previously discussed and as illustrated in Figure 6.12. But gradually, the advantages of hydraulic drive systems began to become known to and accepted by grouting equipment manufacturers, and they eventually gained dominance. The ability to direct

Courtesy of Atlantic Drilling.

Figure 6.12 Mechanically driven diesel-powered grout plant

just the proper amount of power as needed to a variety of functions from a single source is the advantage that makes hydraulic drive today's preferred power distribution system.

Hydraulic drive systems operate by circulating fluid in the form of hydraulic oil through an arrangement of pumps, hoses, valves, motors, cylinders, and so on, to accomplish the work that is to be done. The hydraulic fluid supply is housed in a tank called the reservoir. When the machine is in use, a pump extracts the fluid from the reservoir and circulates it through the system where it is directed to various functions of the machine by valves that allow it to activate those functions, usually motors for rotary motion or cylinders for linear motion.

Figure 6.13 illustrates this principle as applied to a typical grout machine with a colloidal mixer, a rotary grout pump, and two agitators. Figure 6.13 actually depicts two separate hydraulic circuits because the mixing pump motor requires much more fluid than do the rest of the functions, so it was given its own circuit. Each circuit is supplied by a separate section of a dual-section *fixed-displacement* hydraulic pump driven, in this case, by a diesel engine prime power source.

Having been drawn from the reservoir through the suction strainer, on discharge from the pump, the fluid for the mixing pump circuit first encounters a relief valve. This valve is the first line of protection for the circuit and components therein; the valve is spring loaded and pre-adjusted to a specific pressure value of somewhat less than the maximum pressure rating of the least rated component in the circuit. If the circuit pressure

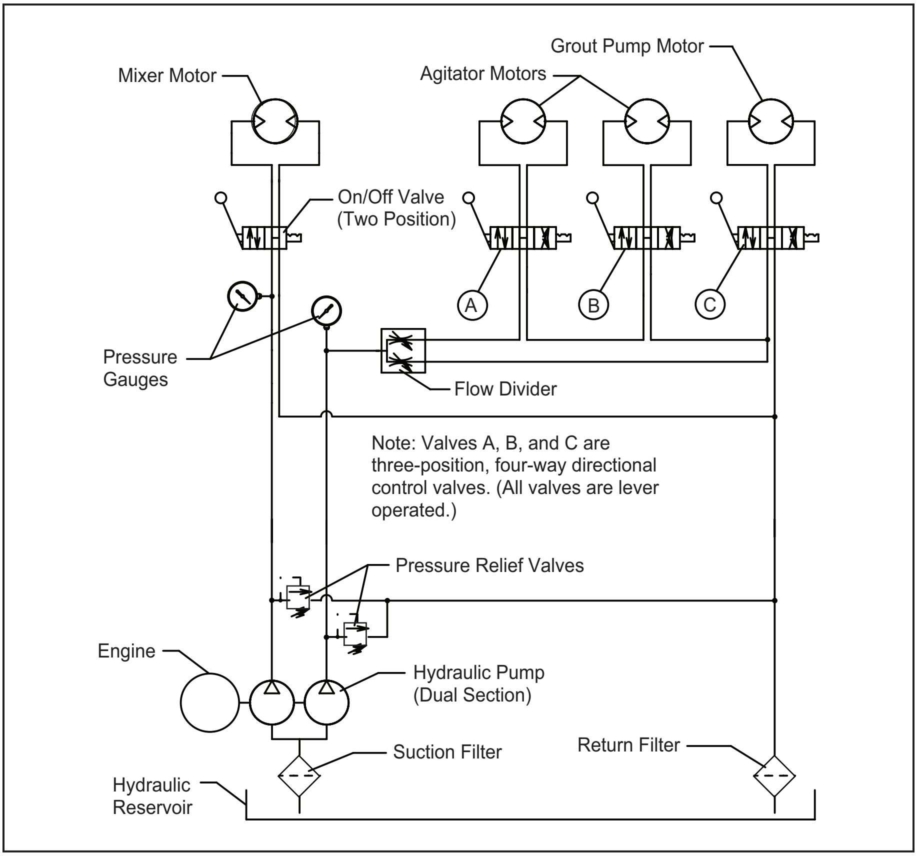


Figure 6.13 Simple hydraulic schematic diagram of a typical grout machine

reaches this point, the valve opens, allowing the fluid to escape back into the reservoir. The circuit pressure is displayed on a pressure gauge located at a place of convenient viewing by the operator.

The next component in the mixing pump circuit is the two-position, lever-operated on/off valve. When this valve is in the Off position, the open center design of the valve offers an unobstructed path for the fluid to return directly to the reservoir. In the On position, the fluid is directed to the motor, enabling materials mixing to occur, whereupon the fluid returns to the reservoir after first passing through the return filter, thus ending the first-circuit journey.

The second circuit handles all of the remaining machine functions. It starts out, as did the first circuit, with fluid passing through the second section of the pump, past the second circuit relief valve previously described, then the second circuit pressure gauge, after which it encounters a flow divider. This device diverts the fluid flow to deliver more

Courtesy of ChemGrout.

Figure 6.14 Hydraulically driven grout plant with onboard diesel power unit

or less oil to the agitator motors, which generally turn slower than their potential speed but occasionally need to turn at top speed, so this valve offers a means to adjust the agitator speed.

The next component encountered by the fluid is the control valve for the first agitator; this is a three-position, four-way directional control valve that has the ability to direct oil in such a way as to make rotation of the agitator paddles in either direction possible. The open center design of this valve also offers unobstructed flow either to the next function or by returning to the reservoir when in the neutral, or Off, position. When actuated in either direction, the fluid flows through the agitator motor before proceeding to the next function in the circuit.

When several functions on the same circuit are served sequentially, it is called a *series circuit*. In Figure 6.13, the fluid next encounters the second agitator before proceeding to the grout pump. The oil diverted away from the agitators by the flow divider has recombined with the return oil from the agitators so that the total flow from the second section of the hydraulic pump is now available to the grout pump motor.

The hydraulic diagram in Figure 6.13 relates to the grout plant shown in Figure 6.14. Hydraulic drive systems generally consist of only a few components, or rather, a few classes of components—reservoirs, pumps, motors, cylinders, valves, hoses, and fittings—but within these classes are a wide variety of choices that make hydraulic drives the most versatile of systems. In addition to versatility, the individual components of a hydraulic system are so robust as to make such a system virtually maintenance free. Other than the occasional broken hose or leaky fitting, there is almost nothing that needs repair—indeed, most of the components are of such design as to preclude the possibility of field repairs in the unlikely event something does fail.

The following sections are limited to descriptions of the most common components used in the manufacture of today's grouting equipment as well as some discussion of how each component works and what function it serves for the machine it is attached to.

Reservoirs

Hydraulic systems operate by circulating a fluid throughout a network of passages created by hoses, fittings, and the components that actually do the work, such as motors, cylinders, valves, and so on. To begin, there must be some receptacle to accommodate that fluid (usually oil) until it is ready for use, and that receptacle is the hydraulic reservoir.

In addition to simply being a passive container, the reservoir must serve other purposes. A filter is usually under the filler cap to ensure that no foreign material enters the tank from the outside. The cap itself is vented to allow air heated by the hot return oil to escape rather than build pressure within the tank. A properly designed reservoir tank allows the hot returning oil to follow a torturous path to slow its return to work, thus providing an opportunity for cooling. Often, a return oil filter will be attached to the reservoir to filter impurities picked up from other parts of the system from the returning oil. In addition, supplemental oil coolers are often installed on the reservoir, particularly if the equipment is to be used in a hot or tropical environment. Far from passive, the reservoir is an active participant in the hydraulic process.

Pumps

In order for the hydraulic medium (oil) to accomplish its work, it must be moving at a volumetric rate and pressure potential sufficient to accomplish the work called for, such as powering a mixer or a grout pump. This is done by means of the hydraulic pump, which draws the oil from the reservoir and propels it through the hydraulic circuit. There are many types of hydraulic pumps, but essentially, no matter what the design, pumps are defined by only two characteristics: pressure and displacement.

The *pressure data* defines the maximum pressure that the pump is capable of producing, and this is basically a measure of potential; in practice, the pump in a well-designed system would seldom, if ever, reach its maximum pressure. The *displacement data* defines the volume of oil that the pump can move, usually in terms of gallons or liters per minute or in terms of cubic inches or cubic centimeters of displacement per revolution.

Pumps may have either a fixed displacement or variable displacement. Although both types are discussed herein, fixed displacement pumps predominate. For the purpose of this manual, discussion is limited to only the more common types of pumps likely to be encountered on popular grouting machines.

Gear Pump

As the name implies, a gear pump consists of a set of two (or more) gears rotating within a case that mesh and unmesh, thus moving the oil through the case and into the hydraulic circuit, as illustrated by Figure 6.15. The gear pump is the simplest and most robust of all hydraulic pumps, having (usually) only two moving parts. Because of its tolerance for

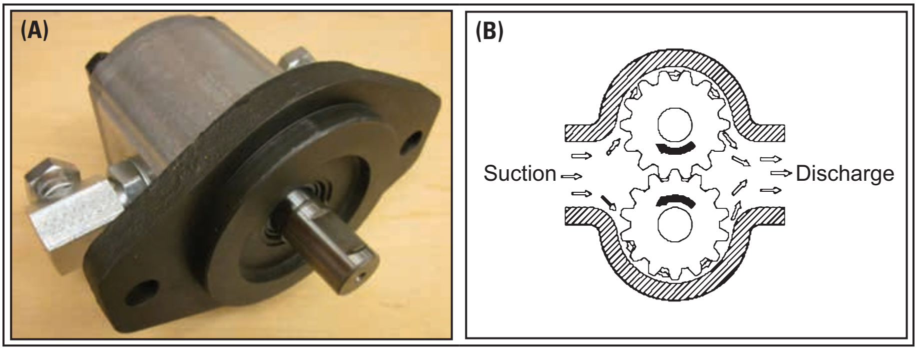


Figure 6.15 Typical (a) gear pump and (b) schematic diagram

dirt and other foreign particles in the oil, it is particularly well suited to dirty and dusty environments such as grouting projects. Gear pumps are usually rated for a specific pressure and speed of rotation that defines the maximum limits of oil delivery rate for these fixed displacement pumps.

These pumps will deliver hydraulic flow continuously as long as a power source, such as an electric motor or a gasoline or diesel engine, maintains rotation. This means that provision must be made to provide unobstructed flow in the hydraulic circuit at all times. Because of their robust construction and relatively low cost, gear pumps are widely employed in the construction of many grouting machines, especially those of more simple design.

Vane Pump

Vane pumps are similar in design to air motors in the sense that they incorporate a rotor with movable vanes rotating within a tightly fitted housing, drawing oil into a void in the housing created by the extension of the vanes and expelling the oil when the vanes are contracted. Vane-type pumps can be either fixed displacement or variable volume. To the best of this author's knowledge, vane-type hydraulic pumps have never been employed in the construction of grouting machines; they are mentioned here solely to acknowledge that they exist.

Piston Pump

Unlike vane pumps, piston pumps are used on hydraulically driven grouting equipment and their utilization for that purpose is indeed on the increase. Since there can be various types of piston pumps, it would be well to specify that those being used on grouting equipment are *variable volume axial piston pumps* (Figure 6.16). What makes these pumps unique and exclusively suited to the demands of grouting equipment is their ability to deliver only the volume of fluid required by the activity at the pressure demanded by the work load. In fact, some of these pumps are so designed and incorporate such controls as to sense the applied loads and automatically adjust to meet or exceed them.


Figure 6.16 Axial piston pump

Design and construction of an axial piston pump is somewhat complex (Figure 6.17), but essentially, the pump consists of a rotating element called a rotor or barrel containing several pistons, usually aligned parallel to the axis of rotation. These pistons act on a movable plate known as a swash plate in such a way as to control the relative motion of the pistons, thus controlling the volumetric discharge of the pump. The greater the angle of the swash plate, the greater the piston movement, thus the greater the discharge rate. When the swash plate is at 90 degrees to the pistons, the discharge rate is zero. Integral sensing valves automatically adjust and control the relative angle of the swash plate.

Figure 6.17 attempts to illustrate the sequential action of the swash plate on the pistons in full volume mode. In the left diagram, the swash plate (A) is fully deflected, allowing one piston (E) to extend, thereby filling its chamber with fluid, while piston B is being compressed by the swash plate, thereby discharging fluid from its chamber. Fluid enters the pump through the inlet port (H) and is directed by the inlet valves (C and F) to each extending piston. As the piston is compressed by the swash plate, the fluid is directed by discharge valves (D and G) to the discharge port (J). As the shaft continues to rotate, pistons are engaged successively and caused to extend or compress, thereby resulting in a continuous flow of oil from the pump. These diagrams are only simple representations; there may be several pistons being acted on in this manner and a more complex valve system being employed in a piston pump.

Figure 6.18 illustrates the position of the swash plate while pumping at half volume and in the neutral position during which there is no discharge from the pump at all. The infinitely variable attribute with respect to flow rate and the ability to “idle” when no fluid is called for by the circuit, along with the load-sensing controls that are usually incorporated into the unit, are the features that make this pump increasingly popular with grouting equipment manufacturers.

In some applications, axial piston designs have been used for motors, but these are not likely to be employed in the construction of grouting machines because of the high cost relative to other equally serviceable components.

Motors

On hydraulically driven grouting equipment, the rotary motive force for mixers, agitators, and pumps is provided by hydraulic motors. Basically, only two types of motors are required for these operations: low-torque, high-speed motors and high-torque, low-speed motors. In general, functions requiring a high-speed rotary motion, such as colloidal mixing pumps, are normally driven by *gear motors*. Other functions that do not require

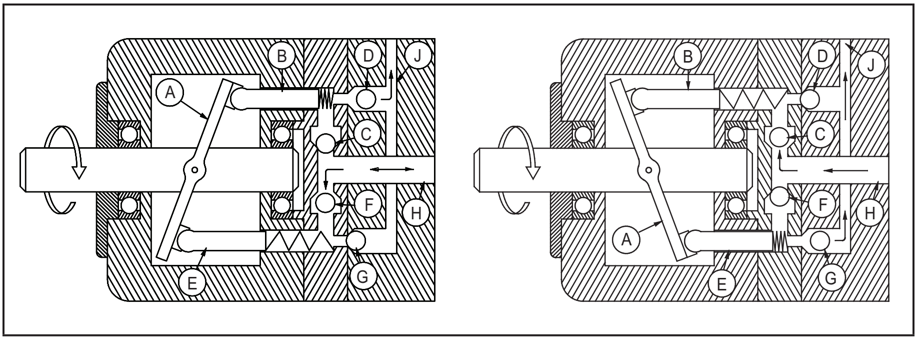


Figure 6.17 Axial piston pump with swash plate at full volume

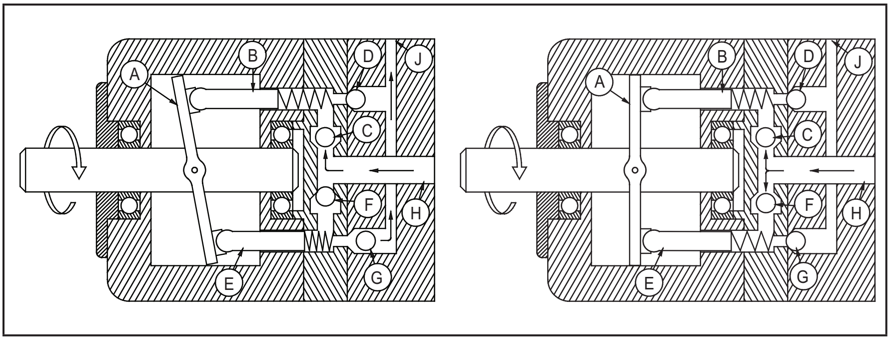


Figure 6.18 Axial piston pump with swash plate at (a) half volume and (b) neutral positions

high speed but may require high starting and running torque, such as progressing cavity grout pumps and, to a lesser degree, paddle mixers and agitators, normally employ *gerotor motors*.

Gear Motor

Although the construction features of gear motors are almost identical to gear pumps, their purpose and activity is exactly the opposite. Whereas the gear pump is driven by some external force for the purpose of propelling hydraulic fluid through a circuit, the gear motor uses the fluid flowing through the circuit to impart rotary motion to another device, such as, for example, a mixing pump. Gear motors have a relatively low starting torque and only reach maximum efficiency at high revolutions per minute, so they are not normally employed in applications requiring high torque.

Gear motors (Figure 6.19) are always fixed displacement and are rated for maximum rotational speed (rpm) and working pressure. The limiting factor with respect to working pressure is generally the integrity of the shaft seals.

Gerotor Motor

A number of motor options are available to produce high-torque, low-speed rotary motion, including piston motors and vane-type motors, but the motor most frequently selected for this purpose by grout plant manufacturers is the gerotor motor (Figure 6.20).

The name "gerotor" is a contraction of the term "generated rotor," which loosely describes the type of motion that the main driving unit, or rotor, performs within the case of the motor. As fluid enters the motor, it acts on an inner rotor that engages with an outer gear, thus allowing the rotor to rotate within the confines of the outer gear while simultaneously engaging a final drive gear that turns the shaft of the motor. Figure 6.21 illustrates this action. The outer ring (gear) remains stationary and the shaft with its associated drive gear remains in the center of the assembly while the rotor moves in a more or less planetary fashion around the inside of the outer ring (gear) while engaging with and rotating the shaft.

Figure 6.19 Hydraulic gear motor

Valves

Hydraulic drive systems employ various types of valves to direct flow to machine functions and control their speeds and direction of travel or rotation. Lever-operated four-way directional control valves are those most frequently encountered on hydraulically driven grout machines of relatively simple design. These are used to actuate specific machine functions such as mixers and agitators and control their speed and direction of rotation.

Figure 6.20 Low-speed, high-torque gerotor motor

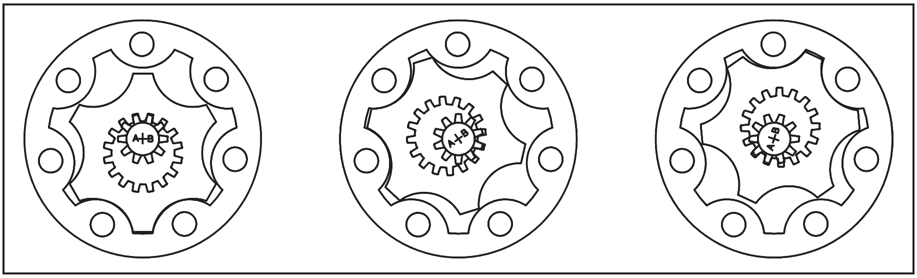


Figure 6.21 Gerotor motor in three stages of rotation

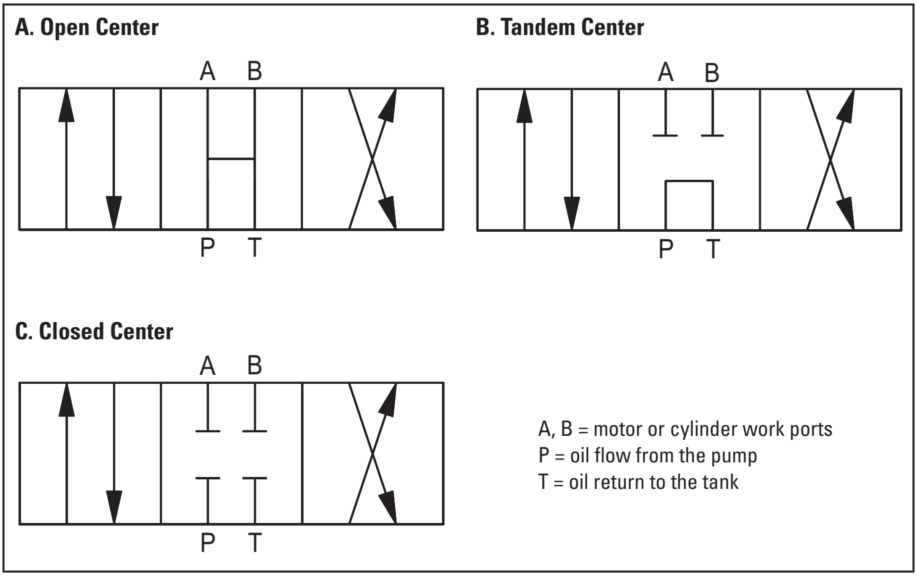


Figure 6.22 Spool options

More complex machines will also incorporate solenoid-operated valves in addition to lever-operated valves.

The lever-operated four-way directional control valves may have mechanical detents in three positions—power to port A, power to port B, and neutral—or may be spring loaded to return to neutral from either port A or port B positions.

Generally, several spool options are available from most manufacturers, including open center, closed center, and tandem center, all with optional metering capability, if desired. Figure 6.22 illustrates the flow patterns of each spool design through the valve.

When the spool is in the neutral position (center), all ports are open, and although fluid is available at all ports, the flow is biased to return to the tank (Figure 6.22a). When the spool shifts to the right, the flow goes through work port A and returns through port B. When the spool shifts left, the flow goes to work port B and returns to the tank via port A. This type of spool would be used on systems with fixed-displacement hydraulic pumps to provide unimpeded continuous flow with the spool in neutral position.

The tandem center spool shown in Figure 6.22b may also be used with fixed-displacement pumps because when the spool is in the neutral position, the flow is sent directly to the tank, but the work ports A and B are blocked to prevent any movement of the function they control. This is particularly important to lock cylinder-actuated functions in place when necessary to support a load, such as some hydraulic door openers.

The closed center spool shown in Figure 6.22c is used with variable-displacement pumps such as axial piston pumps and some vane pumps. When the spool is in neutral position, all ports are blocked, preventing any flow from reaching the work ports

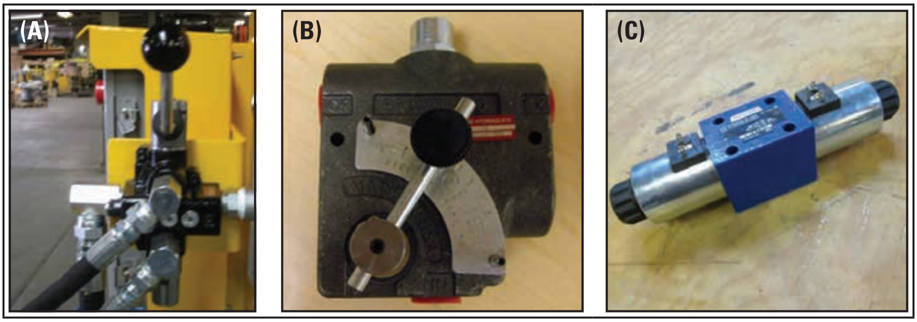


Figure 6.23 Control valves: (a) lever-operated, (b) variable volume, and (c) solenoid-operated

or returning to tank. When the variable-displacement pump senses this, it simply stops pumping. When the spool shifts either to the right or to the left, the pump senses a need for flow and it then produces fluid in the amount and at the pressure demanded by the function that the valve controls.

The lever-operated valves shown in Figure 6.23a work very well for directing hydraulic flow to functions that are intended to keep running throughout a process, such as mixers and agitators. Valves that are equipped with a detent at each of the three positions are particularly well suited to this purpose because once engaged in a position, the valve will hold that position until the operator moves the handle to another position.

Some of these valves also incorporate metering spools that, in addition to the normal On/Off/Reverse functions, allow the valve to control the speed of the activity as well. Many lever-operated directional control valves are also equipped with internal pressure relief to prevent system or component damage due to overpressure.

Another type of valve that is frequently used on grouting equipment is the variable volume flow divider (Figure 6.23b). This valve is normally used to divide a single flow into two separate flows (as illustrated in Figure 6.13), one flow being directed to the work and the other flow bypassing the work. This is often done when the machine function being driven normally requires less flow than is available, but occasionally it will require all of the flow. This valve can be adjusted to deliver all or only part of the hydraulic flow as needed. Moreover, there may be machine designs that require two individual activities to be powered from a single source. Since these valves are pressure compensated, each of the divided flows can be directed to perform work.

Solenoid-operated valves (Figure 6.23c) are most frequently used for reciprocating motion such as that required for operating piston or plunger pumps. The solenoids are powerful electromagnets that shift the valve spool from side to side as needed. Proximity sensors are mounted on the machine in such a manner as to sense the position of the piston in the hydraulic cylinder that drives the pump. When the piston reaches the end of its travel, the appropriate proximity sensor sends an electrical signal to the directional control valve, causing the spool to shift, and the piston then reverses direction. (An example of a

machine that uses multiple proximity sensors to control the reciprocation of a dual cylinder pump is shown in Figure 5.1 of Chapter 5.)

Control of this back-and-forth motion is referred to as timing and is discussed at length in Chapter 4. Although the mechanism to accomplish the timing is different, the principles remain the same: Fluid (or air) must be alternately directed to opposite ends of the drive cylinder to maintain reciprocal motion.

Driving reciprocating pumps hydraulically makes possible many more sophisticated actions, such as automatic pressure regulation, pulsation dampening, and automatic speed control, to name just a few advantages that would not be possible with any other power transmission system.

Hydraulic Fluid

Two kinds of oil come out of the ground: asphalt base and paraffin base. Commercially marketed hydraulic fluids are most frequently made from asphalt-base oil to which certain additives are added to aid in lubrication, reduce foaming, and provide other desirable properties. However, asphalt-base oil starts to deteriorate at about 150°F, and since many hydraulic systems operate at temperatures well above that temperature, the oil loses its effectiveness and must be replaced on a fairly regular basis. This can lead to a disposal problem. The U.S. Environmental Protection Agency considers hydraulic oil to be environmentally hazardous; therefore, used oil must be disposed of in an environmentally responsible manner. This means assignment to a hazardous waste hauler and payment of a sometimes hefty fee (White Drive Products 1991).

On the other hand, automotive motor oil is made from paraffin-base oil and can tolerate temperatures up to 440°F, which is well above the temperature at which most hydraulic systems operate. This oil possesses all of the same attributes of hydraulic oil; therefore, it can be used very effectively as a hydraulic medium. Furthermore, when it finally comes time to change the oil, used motor oil is much easier to dispose of than hydraulic oil because there are more disposal options and much of the oil can be reclaimed (White Drive Products 1991).

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ChemGrout, Inc. 2012. *CG-600/3L6/A Operating and Maintenance Manual*. La Grange Park, IL: ChemGrout.

White Drive Products. January 12, 1991. Hydraulic fluids information. In *White Hydraulics Newsletter 36*. Hopkinsville, KY: White Drive Products.

7
Grout Delivery Systems

Although a hose is the most frequently employed method of transporting grout from the plant to the work site, in some applications hose may be only one component of a grout delivery system that could consist mainly of some kind of pipe or a combination of hose and pipe. In any case, the first consideration in determining what system is best employed for this purpose is to determine what size conduit is appropriate to the application.

Because this manual is intended to be used specifically for field applications, discussions do not involve issues such as Reynolds numbers, Newtonian vs. non-Newtonian fluids, rheology, or any number of other factors that govern and define fluid flow through conduits, subjects that may be appropriate for lab work and thus beyond the scope of this volume. Instead, the discussion revolves around an empirical value learned through observation over many years and found to be almost universally applicable to the transport of suspended solids grouts, such as portland cement slurries and sanded structural grouts.

Suspended solids grout materials tend to coalesce, or drop out of suspension, at linear velocities of less than 3 ft/s. This means that the pumping rate for any such material must exceed this value to keep the material moving at a rate of speed within the turbulent flow regime for the solids to stay in suspension. In other words, to maintain a suspended solids grout material, it must keep moving through the conduit at a linear velocity of between 3 and 5 ft/s. This empirical value will be used to select conduit sizes (diameters), whether hose or pipe, for any grouting application that employs relatively fluid suspended solids grout materials.

FLOW RATES AND CONDUIT DIAMETER

The most often used conduit sizes, either hose or pipe, are 1 inch, 1¼ inches, 1½ inches, and 2 inches. Occasionally, a pipe line may exceed 2 inches in diameter, but usually that is more a function of availability than of flow rate or velocity preference; hose seldom, if ever, exceeds 2 inches in diameter, primarily because it becomes too heavy and awkward to move by hand. Table 7.1 defines minimum flow rates required to maintain turbulent flow for the various conduit sizes available.

Table 7.1 Minimum flow rates to maintain turbulent flow

	Hose			Schedule 40 Pipe		
Internal diameter, in.	Area, in.^{2}	Gallons per minute at 3 fps	Gallons per minute at 5 fps	Area, in.^{2}	Gallons per minute at 3 fps	Gallons per minute at 5 fps
¾	.442	4.13	6.88	.824	5.0	8.3
1	.785	7.34	12.23	1.049	8.08	13.47
1¼	1.227	11.47	19.12	1.380	14.02	23.36
1½	1.767	16.52	27.54	1.610	19.07	31.79
2	3.142	29.38	48.96	2.067	31.67	52.40
2½	4.909	45.90	76.49	2.469	44.86	74.76
3	7.069	66.10	110.16	3.068	70.2	117.0

Courtesy of Ben P. Schatz, ChemGrout, La Grange Park, Illinois.

Given that not every grouting application will accept these flow rates, it is helpful to establish a flow circuit with hose or pipe that allows grout to flow from the grout plant to the work site where an amount of material as required by the work is diverted from the stream, the remainder to return to the grout plant. Figure 7.1 illustrates such a recirculation system. Another advantage to this type of arrangement is that it provides for control at the point of injection.

With this setup, the header operator, who is closest to the work and is thus in the best position to monitor the effect of the grouting operation, has complete control of grouting pressure and flow rate by means of manipulating the bypass flow control valve. Closing the valve restricts the return flow to the grout machine, thereby directing increased flow to the work. If there is sufficient resistance at the injection site, closing this valve will also increase pressure. Conversely, when the valve is opened, more of the supply flow is returned to the grout plant, and the flow (and pressure) at the injection site is reduced.

With complete control of the injection process at the header (shown in detail in the "Other Accessories" section later in this chapter), the grout plant operator needs only to concentrate on material preparation and delivery and is relieved of any other responsibility. In most grouting applications, this is enough of a task to keep one well occupied.

GROUT HOSE

Flexible hose for grouting applications is produced by several manufacturers, usually under the heading of "plaster, grout, and concrete hose." In general, it is a relatively lightweight hose with an abrasion-resistant inner tube (liner), one- or two-ply fabric reinforcement, and a scuff-resistant and ultraviolet (UV)-resistant cover. This is a very durable hose that will withstand years of abuse and still continue to serve its purpose admirably despite receiving only a minimum of care.

Table 7.2 applies to all commonly used plaster, grout, and concrete hose and is typical for grout hoses. In addition to the abrasion-resistant liners, fabric reinforcement, and

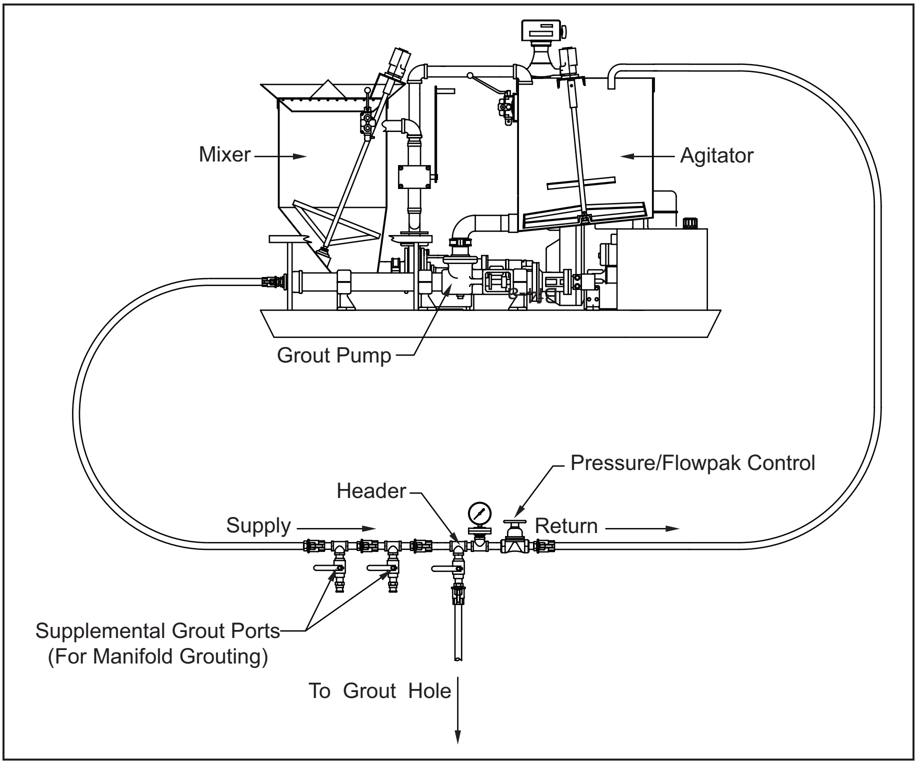


Figure 7.1 Grout circuit arrangement

Table 7.2 Hose specifications

Inside Diameter, in.	Nominal Outside Diameter, in.	Maximum Working Pressure, psi	Weight, lb/ft
1	1.67	1,233	0.67
1¼	1.93	1,233	0.80
1½	2.31	1,233	1.14
2	2.83	1,233	1.46

Source: Adapted from Goodyear Tire and Rubber Company 2012.

scuff- and UV-resistant cover, grout hose also features internally swaged end fittings to provide for unrestricted flow at the joints. Hose is usually available in 25- and 50-foot lengths. Longer lengths are also available, but they are not recommended for grouting service. To obtain their full working pressure capacity, internally swaged NPT ferrules are used to mobilize the full strength of the hose while additionally providing for unimpeded grout flow.

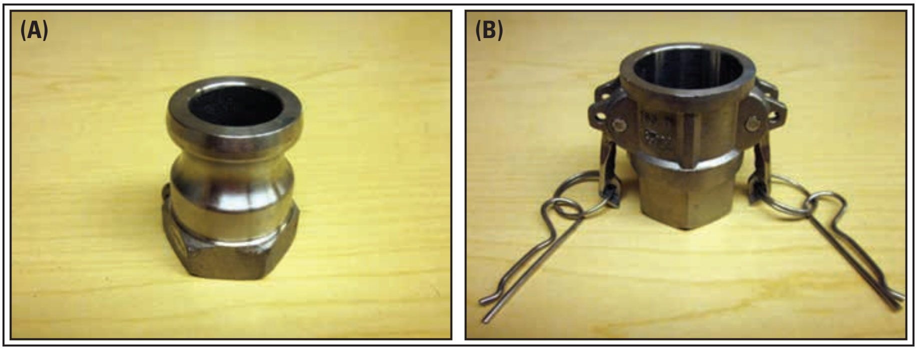


Figure 7.2 Cam and groove style couplings: (a) male and (b) female

This type of hose is available from many dealers and distributors, so there should be no difficulty obtaining sufficient grout hose to satisfy any job-site requirement. Thus, there should be no reason to ever substitute grout hose with air or water hose, which are designed to satisfy completely different application requirements.

One compelling reason for not using air hose for grouting applications is that unless it is thoroughly cleaned after having been used for grouting, when it is again returned to its intended application, residual grout materials deposited on the walls of the hose may be expelled into air-powered machinery, causing damage or accelerated wear to air-driven components.

COUPLINGS

The grout hose can only be as good as the coupling fittings, no matter which manufacturer's hose is selected. These couplings need to have two characteristics: they must have pressure ratings equal to those of the hose, and they must not leak. A third trait is equally important, and that is, they need to be quickly and easily connected and disconnected. Cam and groove style couplings, as shown in Figure 7.2, best satisfy these criteria when used within their working pressure range for low- to medium-pressure grouting applications.

The couplings are available in a variety of configurations, including male pipe thread, female pipe thread, and with hose shank. The hose shank style is not recommended because the shank creates a restriction to smooth grout flow. In an emergency, however, it is handy to have a few available for quick hose repairs when needed.

The necessity for leak-proof couplings cannot be overemphasized. Whether pumping slurries or sanded structural mixes, as the pumping pressure requirement increases, the greater will be the tendency for the liquid fraction (water and/or liquid admixture) to be squeezed out of the mix. This is most likely to happen at a leaky joint, and if it does happen, there is a good possibility that a grout plug or sand block will occur at that location.

Other types of couplings are also available. Some operators have used pipe unions. However, from this author's experience, opting for the cam and groove couplings is the

best choice because they work well in all applications in which they are used within their working pressure range, and they are more easily coupled and uncoupled. Cam and groove couplings are made by several manufacturers, both foreign and domestic, and are available in a wide range of materials, including brass, aluminum, high-carbon tool steel, stainless steel, and others, including high-strength plastics. These couplings are available from most industrial supply companies.

Figure 7.3 Detail of water fitting

Be advised that each coupling type has a rated pressure capacity, and for safety's sake, a prudent operator will research the type of coupling and the material from which it is made to make sure it will be compatible with the application. A general survey of cam and groove coupling manufacturers reveals that this type of coupling may be used for service with pressure ranges between 100 psi and 250 psi, depending on size and material from which it is manufactured.

Some grouting applications may require pressures in excess of the rated capacity of either the grout hose or the coupling, or both. When this is the case, a higher-strength hose and a different type of coupling are required. High-pressure hoses with grooved steel ends and clamped or bolted couplings are available from many sources and have been used very safely and successfully for pressures in the range of 500 to 750 psi.

In some cases, the required pressure range for the grouting application may even exceed the previously stated numbers, and when this occurs, the most expedient and economical means to ensure a safe operation has been to use readily available high-pressure hydraulic hose and threaded couplings for grouting service. It is not the ideal use of the hose since it was not manufactured for abrasive service, but it will provide a sufficient safety factor.

In the event that a plug or sand block develops, it is recommended that your grouting toolbox contain a 50-foot length of ⅜-inch-diameter soft copper refrigeration tubing with a valve and a fitting compatible with the water supply line. The fitting shown in Figure 7.3 is for a garden hose, but any kind of fitting can be adapted. The copper tubing is soft enough to be rolled into a coil, so it will not require much toolbox space. Should you encounter a grout plug or sand block, the steps shown in Figure 7.4 can be followed to clear the blockage. The inexpensive expedient of having a length of copper tubing available in the event of ever being faced with having to clear a plugged hose will save time, effort, and frustration; it will be one of the best tool investments you'll ever make.

STEEL PIPE

Some grouting applications, such as mining and other underground construction projects, require that grout be pumped long distances, sometimes up to 15,000 feet. Steel

1. Relieve the pressure on the grout line. If you can reverse the pump (progressing cavity pump only), do that, but if you cannot, then open the pressure relief valve.
2. Having relieved the pressure, feel the hose—either by hand or with the heel of a boot—to determine where the hose gets hard to the touch, then open the coupling closest to that location.
3. Unroll the copper tube that you have so carefully guarded in the toolbox for months and connect it to a water source.
4. With water running through the tube, insert the tube into the plugged hose and continue to wash until it is clear.
5. Re-couple the hose and return to work.

DO NOT...

...Beat the hose with a sledge hammer. Doing so will not break the plug, but it will damage the hose.

...Run over the hose with a pickup truck, end loader, pavement roller, or any other vehicle. You've already tried beating it with a hammer; running it over with a vehicle will not be productive.

...Hang it from a crane in the hopes that the plug will simply drop out of its own accord.

Above all...DO NOT attempt to force it out with a high-pressure pump. This is highly dangerous and can result in damage to the hose and possible injury to personnel.

Figure 7.4 Procedure for removing a grout plug or sand block

tubing, commonly referred to as "slickline," is most frequently used for pumping long distances because of its inherent high strength and smooth walls that offer less resistance to rapidly moving grout materials. The same consideration for sufficient linear velocity to keep solid particles in suspension applies to pipe as it does for hose; that is, the linear velocity of a suspended particle (portland cement) grout should be maintained between 3 and 5 ft/s. In consideration of this, and with the knowledge that portland cement–based grouts are very abrasive, it would be wise on the part of a grouting practitioner to use a pipe specifically designed for grout or concrete delivery for this purpose.

Some long-distance pumping applications have employed standard Schedule 80 black pipe and plain couplings to successfully pump portland cement–based grouts for distances in excess of 10,000 feet, but should plugs occur in the pipe, unthreading the couplings is an extremely laborious process; therefore, using standard pipe is not recommended.

Steel pipe slickline is a high-strength, abrasion-resistant pipe specifically made for pumping concrete. It is relatively lightweight (11 Ga. minimum wall thickness) and features heavy-duty raised ends to accommodate high-strength clamp-and-gasket-style couplings that may be easily disengaged and uncoupled should the need arise. This pipe is available from several concrete pump distributors and comes in inside diameters from 1½ to 5 inches and in 5- or 10-foot lengths. Also available are 45- and 90-degree elbows,

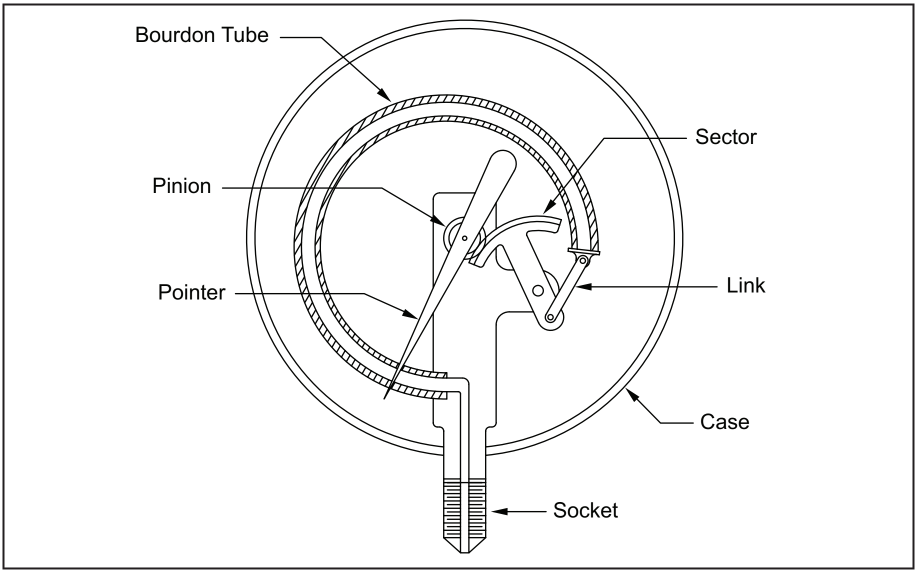


Figure 7.5 Bourdon tube pressure gauge

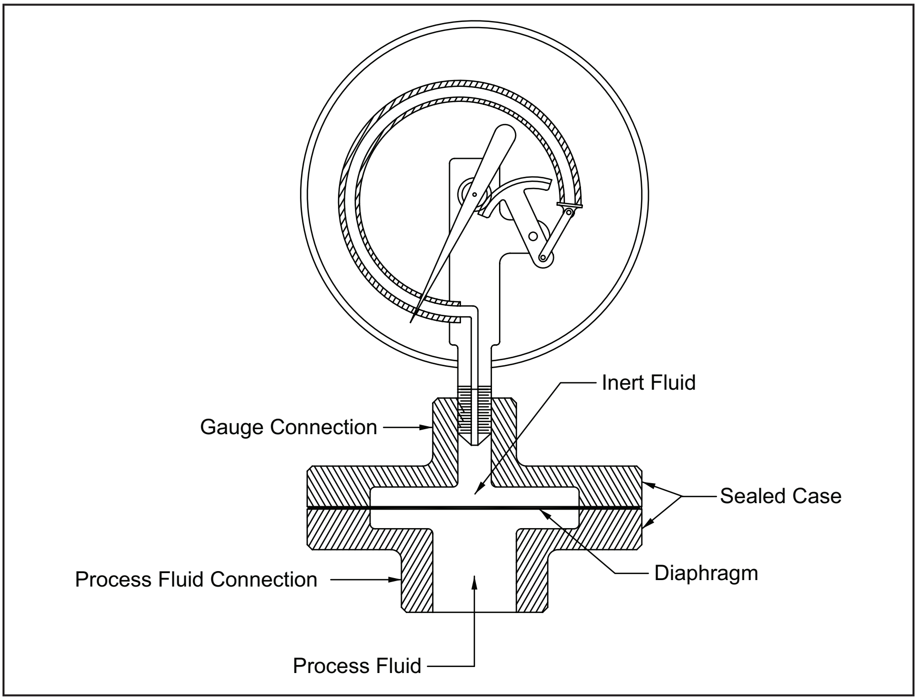


Figure 7.6 Gauge saver

sweep bends, and other specialty pipe accessories. As the pipe diameter increases to 4 inches and greater, heavier wall thicknesses are available.

Given that 1½ inches is the minimum diameter available, it is necessary to have a pump capable of delivering an average of 25 gpm (refer to Table 7.1) to maintain turbulent flow and avoid siltation problems in the line. If a larger-diameter pipe is chosen, the pump capacity must be increased accordingly.

PRESSURE GAUGES

The two most important parameters of any grouting program are flow rate and pressure. Flow rate may be calculated on the basis of some measurement, such as the depth of grout remaining in an agitator or mixer tank, or by a direct meter reading, and pressure may be read directly from a gauge.

Generally, the gauges most frequently used for this purpose are known as Bourdon tube gauges (Figure 7.5). Essentially, the Bourdon tube gauge consists of a curved metal tube linked to a sector gear that engages a pinion to which a pointer is attached. Process fluid enters the tube through the socket that is connected to the source by means of a threaded connection; as the fluid pressure is increased, the C-shaped Bourdon tube tends to straighten, moving the sector, which in turn rotates the pinion, causing the pointer to move, thus visually indicating the pressure of the process fluid.

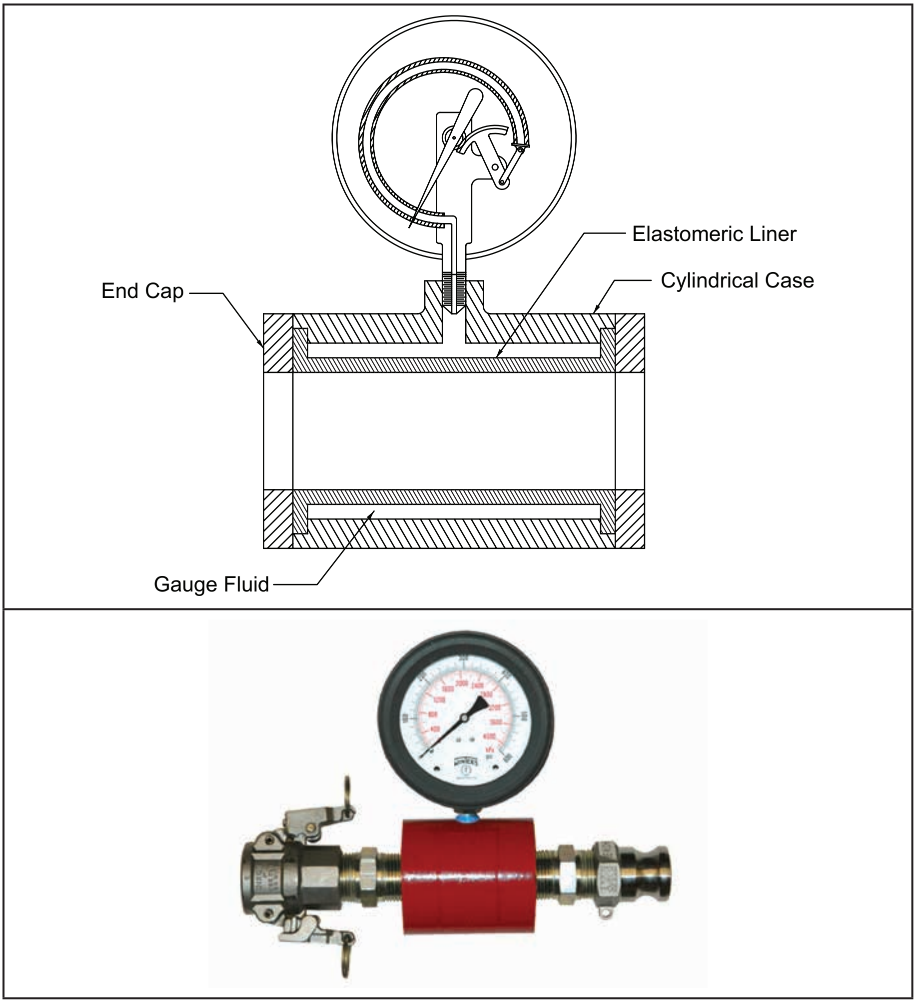
The process fluid in this case is portland cement–based grout, which, if it were to enter the Bourdon tube, would harden there and render the gauge unusable. Therefore, it is necessary to isolate the gauge from the process fluid (grout) by means of another device popularly known as a "gauge saver" (Figure 7.6).

Since keeping grout out of gauges has been a problem for as long as the grouting industry has existed, there have been many approaches tried over the years, but the one seen most frequently consists of a diaphragm sealed within a metal container with a small volume of inert liquid (usually glycerin) to actuate the gauge. The process fluid enters the sealed case through a port, usually a threaded fitting or clamping device at the bottom of the sealed case, which is somewhat larger than the gauge fitting to facilitate cleaning. The process material acts on the diaphragm, which in turn acts on the inert fluid, which actuates the gauge.

Figure 7.7 depicts a different style of gauge with a gauge saver installed. This style is known as a "seal" but functions in the same manner as the gauge saver illustrated in Figure 7.6 and both are intended to accomplish the same

Courtesy of ChemGrout.

Figure 7.7 Protected pressure gauge (seal)

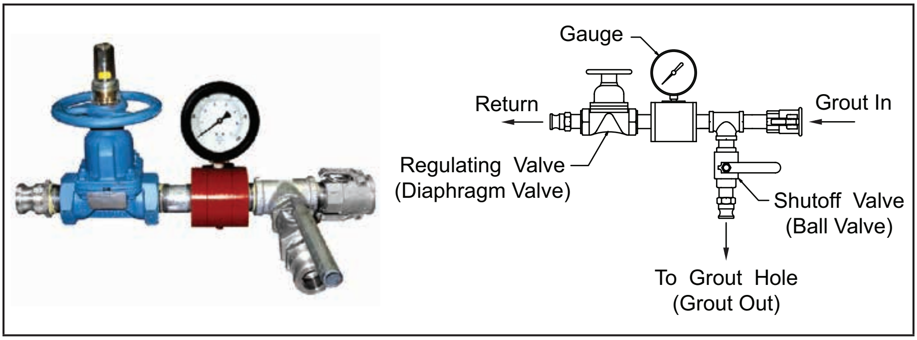


Courtesy of ChemGrout.

Figure 7.8 Inline gauge saver

thing; that is, to accurately report the pressure of the process material while protecting the gauge from being damaged by the grout.

Of course, it is possible that the process side of even the gauge saver can become filled with grout that hardens in place. If that happens, the gauge saver is no longer usable and almost always must be discarded. Sometimes it is possible to retain the gauge in those cases, but the gauge will then have to be mounted on a new gauge saver. The gauge (inert) fluid must completely fill the Bourdon tube and the upper chamber of the gauge saver



Courtesy of ChemGrout.

Figure 7.9 Grout header and detail

with no remaining air space; as this is almost impossible to accomplish in the field, the gauge must be returned to a facility that is equipped to do that type of work.

There is, however, another alternative in the form of an inline gauge saver (Figure 7.8). Essentially, it consists of a cylindrical steel tube with an elastomeric liner and a space in which the inert fluid can be injected. There is also a threaded fitting for the gauge. The process fluid (grout) flows through the tube unimpeded while the elastomer expands in response to the grout pressure, causing displacement of some of the gauge fluid, thus actuating the gauge.

The most obvious advantage to this type of gauge protection is that there is absolutely no possibility of the process fluid (portland cement grout) entering any part of the gauge, as it is completely isolated from the process fluid by means of the elastomeric tube and the inert gauge fluid. The greatest disadvantage is the cost of this device, which can be many times (up to four times) the cost of diaphragm-type protectors. Nevertheless, this author believes that the advantages far outweigh the difference in cost.

As is also true of the diaphragm-type protectors, should the gauge itself become damaged or destroyed, the entire unit must be sent to a facility that is properly equipped to evacuate all of the air from the system and replace the gauge fluid as well as the gauge.

OTHER ACCESSORIES

To complete the grout delivery system, a few other accessories are needed. The grout header called out in the grout circuit arrangement depicted in Figure 7.1 is illustrated in detail in Figure 7.9. This device allows a skilled header operator to maintain a constant pressure on a geologic feature being grouted through an ever-changing flow rate regime by means of manipulating the grout return throttling valve, thus directing more or less grout to the work as needed until the grouting procedure is completed.

Of course, there must also be a means to connect the grout hose to the work, whether grouting through concrete or rock, or into soil, and this is generally the work of some kind of packer. Three types of packers are in common use today: drive packers, mechanical packers, and inflatable packers.

The drive packer (Figure 7.10) is the simplest, consisting of a tapered pipe with a female grout hose coupling and shutoff valve, and is used for relatively low-pressure (<200 psi) applications in competent rock or concrete. A hole is drilled of a diameter just slightly smaller than the outside diameter of the pipe, and the pipe is wedged into the hole with several blows of a heavy hammer. This type of packer is most often used for void filling under concrete slabs and slab-raising applications; however, a similar type of drive packer has been used for backfill and contact grouting of tunnel liners.

Courtesy of ChemGrout.

Figure 7.10 Drive packer

The mechanical packer (Figure 7.11) consists of a center tube (or core pipe) to which is threaded a grout hose coupling and a shutoff valve. A rubber expansion element is affixed at the opposite end and is expanded by means of a concentric tube being forced downward by the action of a spinner (handles) being threaded against the tube. When this packer is inserted into a hole drilled in either concrete or rock, the expansion element is forced against the inside wall of the hole, thus holding it securely in place as shown in Figure 7.12. This packer will withstand somewhat greater pressures than the drive packer, depending on the hole size and expansion element design. These are adaptable to many different hole diameters and hole depths up to a certain limit, as determined by available pipe lengths, generally 20 feet.

Courtesy of ChemGrout.

Figure 7.11 Mechanical packer

The inflatable packer is the most versatile of the three types of packers in that it has a variety of uses in several applications, from exploratory testing to water well development, to oil well applications, to rock and soil grouting, and many more. The typical inflatable packer (Figure 7.13) is built on a mandrel pipe with one fixed end and one sliding end. Between these is an elastomeric expansion element. The fixed end, which is equipped with the ports through which the inflation medium is introduced, is usually on top when the packer is used for a downhole application.

When the packer is inflated, the expansion element is forced against the walls of the drill hole or casing pipe in which it was installed and held there tightly by the pressure of the inflation medium, which is often an inert gas, such

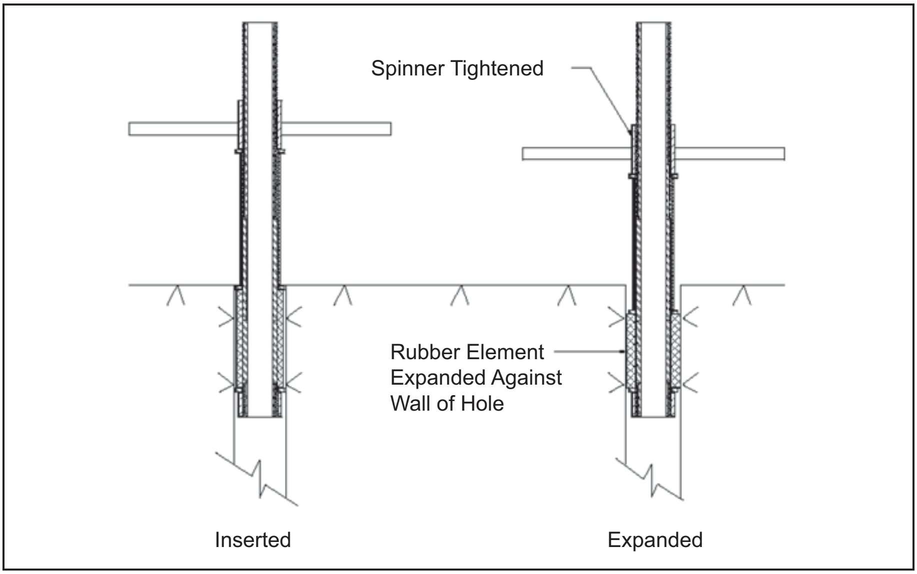


Figure 7.12 Mechanical packer installation

Courtesy of ChemGrout.

Figure 7.13 Inflatable packers

as nitrogen, but could also be water or some other medium. As the element expands, it also shortens, drawing the sliding end toward the middle, or upward if the packer is in a downhole application. Once inflated, the inflatable packer is capable of resisting grout pressures of many thousands of pounds per square inch. When used in combination with perforated tubes called "tubes à manchette" (or sometimes called "sleeve pipes"), inflatable packers may even be used to grout certain permeable soils and other formations.

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Appendix
Grouting Equipment Suppliers and Manufacturers

SUPPLIERS

Company	Website	Products
Atlas Copco USA	www.atlascopco.com/us/	Air compressors Air motors Automated grout plants Craelius grouting equipment Mining equipment Rock drills
ChemGrout, Inc. La Grange Park, Illinois, USA	www.chemgrout.com	Accessories ChemGrout grouting equipment Grout hoses Packers
Con-Tech Systems, Inc. Delta, British Columbia, Canada	www.contechsystems.com	Accessories Ground support and tieback bars Grout hoses Grout monitoring and recording devices Obermann grouting equipment
DSI Underground Systems Bristol, Virginia, USA	www.dsiunderground.com	Ground support systems Grout monitoring and recording devices Häny grouting equipment Resins and grouts Rock bolts and cable bolts Threadbar
Team Mixing Technologies Abbotsford, British Columbia, Canada	www.teammixing.com	Automated batching plants Automated grout plants Cemented rockfill plants High-capacity colloidal mixers Keller Colcrete mixers Material handling equipment

MANUFACTURERS

Company	Website	Products
Atlas Copco Craelius Marsta, Sweden	www.atlascopco.com/craelius	Agitators Colloidal mixers Complete grout plants Computer-controlled grout plants Diamond drill bits Drills and drilling supplies Plunger pumps Recording monitoring systems Recording systems
ChemGrout, Inc. La Grange Park, Illinois, USA	www.chemgrout.com	Colloidal mixers Complete grout plants Packers and accessories Paddle mixers Piston pumps Plunger pumps Progressing cavity pumps
Colcrete Eurodrill Derbyshire, United Kingdom	www.colcrete-eurodrill.com	Agitators Colloidal mixers (mills) Complete grout plants Drilling equipment and supplies Piston pumps Plunger pumps
Häny AG Meilen, Switzerland	www.haeny.com	Agitators Automated grout plants Colloidal mixers Complete grout plants Packers and accessories Recording and monitoring systems Single and double plunger pumps
Obermann Grout Systems (Obermann GmbH) Brensbach, Germany	www.obermann.com	Agitators Automated grout plants Complete grout plants Drilling equipment Jet grouting equipment Mixers Recording and monitoring systems Single and double plunger pumps

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About the Author

Donald C. Hegebarth's long association with the grouting industry began in the early 1960s with employment at a major grouting contractor with global operations, where he learned the basics of almost all grouting practices of the time. Since then, Don's put his grouting experience to use first as a superintendent for a major tunnel construction contractor, then for 7 years as an independent consultant to construction companies and other entities tasked with grouting projects in locations such as Hong Kong, Singapore, and Viet Nam, as well as in the United States.

Finally, he capped his career as the technical manager for a domestic grouting equipment manufacturer where he created several patented equipment innovations, retiring at age 70 after 20 years of service with that company. Since 1998, Don's been associated with the annual grouting short course presented at the Colorado School of Mines.

GROUTING EQUIPMENT MANUAL

SELECTION, OPERATION, MAINTENANCE, AND REPAIR

by Donald C. Hegebarth

Pressure grouting is an essential construction procedure that is practiced by contractors and engineers around the world. Used since the 19th century, grouting reduces the amount of leakage through rock for dam foundations and underground works. It also strengthens soils to provide a stable foundation to support the weight of surface structures, such as buildings, bridges, and storage tanks. In addition, it is frequently used to repair deteriorated concrete and to produce concrete underwater.

This manual introduces various types of equipment employed in pressure grouting applications performed in geotechnical works and examines the operating principles and maintenance issues relative to each equipment type.

The term *pressure grouting* encompasses a wide variety of applications and operations, including dam foundation grouting, soil stabilization and permeation, consolidation and compaction grouting (except low-mobility), water cutoff and structural stabilization in rock tunnels, deep foundations via drilled piers, underwater concrete, structural concrete repairs, raising of settled slabs and structures, rock and soil anchors, and machine foundations and bases. The applications for pressure grouting operations are almost limitless, as the equipment can be employed anywhere fluid grout can be used.

Primarily intended for machine operators and maintenance mechanics, this manual will also prove useful to specification writers, engineers, contractors, purchasing managers, and others who have a responsibility to specify, acquire, operate, or maintain pressure grouting equipment. Topics covered include mixers, agitators, pumps, delivery systems and accessories, but not electronic monitoring and other ancillary equipment.

This manual will help grouting machine operators perform their work without unnecessary stoppages from equipment failures, so a main focus is maintenance and repair of the various components common to most grouting equipment. Generic examples are used and are not intended to be specific to any particular machine.

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